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A Summary of Current Program 7/1/64 and Preliminary Report of Progress for 7/1/63 to 6/30/64

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FOREST SERVICE

of the

UNITED STATES DEPARTMENT OF AGRICULTURE

and related work of the

STATE AGRICULTURAL EXPERIMENT STATIONS

This progress report is primarily a tool for use of scientists and administrators in program coordination, development and evaluation; and for use of advisory committees in program review and development of recommendations for future research programs.

The summaries of progress on USDA and cooperative research include some tentative results that have not been tested sufficently to justify general release. Such findings, when adequately confirmed, will be released promptly through established channels. Because of this, the report is not intended for publication and should not be referred to in literature citations. Copies are distributed only to members of Department staff, advisory committee members and others having a special interest in the development of public agricultural research programs.

This report also includes a list of publications reporting results of USDA and cooperative research issued between July 1, 1963, and June 30, 1964. This progress report was compiled in the Forest Service, U. S. Department of Agriculture, Washington, D. C.

UNITED STATES DEPARTMENT OF AGRICULTURE

Washington, D. C.

July 1, 1964

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INTRODUCTION

This report summarizes progress during the past year in the forestry research program of the Department of Agriculture. Included is research carried on directly by Department scientists and that done cooperatively with other agencies. A summary of new information for each subject matter area is followed by a list of pertinent publications. The report concludes with a tabulation of currently active research projects.

The Department's research program provides the basis for management of the National Forests and National Grasslands by the Forest Service. It furnishes the technical base for protecting, developing and utilizing the resources of forest and range lands administered by other Federal agencies. And it contributes in large measure to the fund of knowledge on which depends effective management of all the nations' forest lands and the utilization of forest products.

The National Forestry Research Advisory Committee annually reviews the forestry research of the Department of Agriculture. Progress during the past year and plans for the year ahead are discussed. The aim is to concentrate available resources on the more pressing problems and at the same time maintain proper balance toward achieving long range objectives. Coordination of research efforts receives attention.

Research undertaken directly by Department scientists is conducted at the national headquarters, Washington, D. C.; at the Forest Products Laboratory, Madison, Wisconsin; at ten Regional Forest Experiment Stations which carry out projects at a number of locations throughout the United States; and at the Institute of Tropical Forestry in Puerto Rico. Most of the research is headquartered on or near the campuses of colleges and universities. There are 350 active projects requiring about 1,000 man-years of professional effort.

Brief summaries included in the report describe ongoing Hatch Act research in forestry and related fields at the state agricultural experiment stations. Altogether there are 218 active projects in 43 state agricultural experiment stations. Many of the individual projects contribute formally to the objectives of regional projects, with the project leaders meeting together annually. There are existing forestry regional projects in forest genetics and tree improvement, ecology and economics.

The summaries do not this year include research under the McIntire-Stennis program, recently initiated. To date 192 projects are active under this program, which is also administered by the Cooperative State Research Service. Also excluded from this report is non-Federal forestry research at the agricultural experiment stations. There are currently at least 288 forestry projects at the state stations which do not receive Federal funds.

Department research effort extends from the initial development of information to its application. Examples from the past year follow:

New Seed Coating Reduces Pesticide Hazard. Direct seeding continues to be an important method of regenerating forest land to new tree crops. Last year, over 220,000 acres were direct seeded in the United States, primarily in the Southern and the Pacific Northwest regions. A new and improved seed coating for repelling birds and rodents has been developed at Alexandria, Louisiana. This aqueous suspension of thiram is easier and simpler to apply and more durable than the previous dry process; of even more importance, it is safer to use because it gives off no chemical dust. This new repellent technique promises to be an outstanding contribution to the increasingly important direct seeding operations on timber lands.

Cheaper Timber Stand Improvement Methods. Important advances in timber stand improvement practices in recent years have been possible through techniques developed by forest research. An example of improved technique involves the use of the less expensive undiluted 2,4-D amine instead of formulations of 2,4,5-T ester in tree injector treatments of cull trees. By using these less expensive and more effective methods of killing unwanted shrubs and trees, timber landowners are treating thousands of acres annually to improve the composition and quality of young timber stands. In 1963, for example, nearly 600,000 acres of National Forest land were treated for tree release, thinning, or pruning. In the State of Georgia alone, 375,000 acres of timber land, mostly in industrial holdings, were treated last year. Improving the composition, quality, and stock of young timber stands significantly increases forest production.

Better Seed for Pine Gum Orchards. Tree improvement research aimed at increasing gum naval stores production has been in progress since the early 1940's when the first high-yielding parent trees were selected. Offspring from planned breeding among these selected trees showed a strong inheritance of high gum production. Some individuals were as much as 100 per cent above the forest-run trees and all of them averaged 50 per cent above. Selections from the best of these offspring were used for breeding a second generation of progenies which now are three years old and promise further improvement in gum yields.

To get superior seed produced for commercial use, while the breeding program continues, seed orchards were established by vegetative propagation methods from the best of the first progeny stock. These orchards, sponsored by State, Federal, and industrial cooperators, will reach seed production age within three years and begin supplying pedigreed seed to the naval stores region.

Watershed Protection Data Applied. A major objective of watershed management is to increase the quantity of water yield while maintaining or improving water quality to meet current and potential demands. A cooperative Road Erosion study in the northern Rocky Mountains has provided information used in preparation of a regional handbook containing standards for locating, constructing, and maintaining logging access roads and skidtrails to reduce erosion and sedimentation. Similarly, range protection criteria, developed by research, have been incorporated into the range management handbook for the same region.

Winter deer range restored and rejuvenated. Findings from research in Utah are being applied in the restoration or rejuvenation of Great Basin winter deer ranges. One method widely used on thousands of acres of pinon-juniper woodland consists of uprooting the trees by chaining, broadcast seeding to crested wheatgrass by airplane, hand spot-seeding to bitterbrush, Stansbury cliffrose, and fourwing saltbush within pits left on removal of stumps, then rechaining the area for coverage of seed. Another developed method now being used to rejuvenate decadent stands of bitterbrush or serviceberry mixed with sagebrush is by use of the Dixie drag. Sagebrush is uprooted but not the highly desirable bitterbrush or serviceberry. The latter species sprout profusely, vigor is restored, and production of browse greatly increased.

Successful applications of recreation research results. Two years ago, the Northeastern Station developed a flame-actuated convection current device for keeping pit toilets odor free. (Wagar, 1963) Despite the fact the subject of toilets is not an exciting one, the problem is nonetheless real. Wagar's publication has been in great demand throughout the country, and in addition to many "home-made" adaptations, at least two firms are marketing the device on a commercial basis.

The knowledge by the Southeastern Station that hardwoods are generally more resistant to heavy recreation use than conifers, that rhododendron and its relatives can endure heavy use better than many other shrubs (Ripley, 1962), is finding its way into the planning and establishment of campgrounds in several sections of the east and southeast.

The double-sampling system using highway traffic counters to estimate recreation visits and to relate traffic counts to type and amount of recreation use has been successfully and widely adopted in the Southeast. The method is now under trial in several park and forest systems in other sections of the country.

Progress made in fire weather studies. Study in slow motion of high speed records of the electrical discharges in lightning strikes has shown wide variation in the details of discharges and the probability that only some types of strikes may have fire-starting capabilities. Cloud seeding may possibly alter these fire-starting characteristics.

The occurrence of high fire danger has been successfully correlated with distinctive synoptic weather patterns for each of 14 climatic regions of the United States. Analysis of the weather maps produced currently at the National Weather Center quickly indicates areas of the country where the fire potential is high and areas that are relatively safe from catastrophic fires.

Study of how and when to burn for hazard reduction in Southern pine stands has identified the best fuel moisture and relative humidity conditions. Satisfactory fuel moistures range from 5 to 14 per cent (optimum about 8) and relative humidities from 30 to 60 per cent (optimum about 40).

A method of mass rearing of the southern pine beetle perfected. During past years, research on the biology and control of the southern pine beetle, one of the most destructive forest pests in this country, has been seriously hampered by the inability to maintain a continuous supply of an adequate number of beetles for study purposes. This has occurred because of the lack of a method of rearing the species. During the past year this obstacle was finally overcome through research and it is now possible to rear adequate numbers of beetles on a continuous, year-round basis under controlled conditions. This should greatly facilitate needed research on such basic problems as the fertility and fecundity of the beetle, the genetical effects of crossbreeding and inbreeding, its nutritional requirements and on its parasitic and predaceous enemies.

Powerful sex attractant produced by female carpenterworm moths. It has been learned that virgin female carpenterworm moths secrete an extremely potent odor that attracts male moths for mating. For example, a single female moth placed in a cage in a wooded area in Mississippi attracted 316 males into the trap in 5 days. Several marked males were attracted and trapped after release as far away as 1/2 mile. This finding may lead to the synthesis of the attractant material and to the development of a cheap, safe, and effective method of reducing or preventing damage by carpenterworms to valuable living hardwoods in the Deep South.

Characteristics of spruce-fir stands influence spruce budworm damage in the Lake States. Studies recently completed in the Lake States have shown that the amount of damage resulting from spruce budworm defoliation in spruce-fir stands is strongly influenced by stand characteristics. For example, in mixed stands containing not only spruce and fir but also various other tree species not fed upon by the budworm, such as aspen, birch and pine, damage was slight to spruce and fir growing beneath or in the shade of the non-host trees. In contrast, damage was severe to spruce and fir growing in the open, though only a few yards away. Further research may reveal how to incorporate this finding into recommendations for the management of these stands in ways to prevent destructive outbreaks from occurring.

Progress on oak wilt control. Oak wilt infected logs can effectively be decontaminated by simple fumigation with methyl bromide under a plastic sheet. Logs so treated would no longer be hazardous for international shipment even to those countries now having embargoes against the import of oak logs from the wilt infected area of the United States.

Completion of a 5-year study of the effectiveness of oak wilt control efforts has uncovered convincing evidence that this important disease is much more virulent and severe in an area of northeastern West Virginia, western Maryland, and south-central Pennsylvania than elsewhere in its south-central and eastern range.

More difficult Fomes annosus control indicated. Indications that Fomes annosus spores may wash down through the litter and soil to infect pine roots directly have serious implications to control efforts. Currently recommended prophylactic treatment of freshly cut stump surfaces to control this important root rot, based largely on European experience, may be ineffective. Alternative controls are being developed. Serological techniques using rabbits as test animals will detect differences in specific antigens distinctive enough to be useful in distinguishing Fomes annosus even from other closely related fungi. Identification of the causal fungus from among the myriads of other soil-inhabiting microorganisms is essential to studies of infection and spread of this most important root disease.

Southern pine plywood industry becoming established. A new southern pine plywood industry has resulted from forest products research, some of it conducted almost 20 years ago. Early research predicted that the technical problems in producing veneer and plywood from southern pine were not insurmountable, but the timber supply situation was not favorable and new developments were needed in equipment for efficient handling of small logs. In 1962 the timber supply situation appeared to be favorable and new studies of veneer cutting, drying, and gluing provided the know-how for the manufacture of sheathing grade southern pine plywood. Commercial production was begun within the past year at one plant. Two more new plants are nearing completion and at least five more are definitely committed. It is currently estimated that this new industry will be providing employment for over 1,500 people, will use perhaps 150 million board feet of timber annually, and will produce $20 to $25 million worth of plywood annually by the end of 1964.

Balloon logging shows promise. The completion of a feasibility study of balloon logging points the way to more economical and more efficient ways of moving large logs in rough country. This study represents the first large scale application of systems engineering research to logging problems. Not only does the study provide data needed to justify some field trials of the new method, but it also pioneers new research techniques.

Forest Survey aids industry planning. The recent decisions of several companies to locate new softwood plywood plants in the Midsouth were based in part upon forest survey statistics which indicated the adequacy of supplies of suitable pine saw-timber. Forest survey data are in continuous use by forest industries in planning wood procurement and forestry programs and in determining the location of new plants or the expansion of plant facilities.

Marketing improved with weight scaling. Studies in the South on weight scaling of saw logs and pulpwood have indicated that substantial savings are possible from weight scaling and have stimulated adoption of this improved marketing practice at more than 100 installations.

I. TIMBER MANAGEMENT RESEARCH

A. SILVICULTURE

Problem

The broad field of silviculture includes the problems of growing and tending forest trees and stands from seedlings to sawtimber. It deals with reproducing forests both naturally and artifically, with intensive cultural measures for improving the yield and quality of forest stands, with methods for evaluating and improving the productive capacity of forest soils, and with cutting methods required to perpetuate valuable species adapted to the site. Related to all of these problems are the basic physiological processes involved in tree growth.

Evaluation of soils and sites for the establishment, growth, and development of various tree species is basic to intelligent forest management. Knowledge of proper species or mixtures best adapted to particular sites is needed to guide regeneration programs, timber stand improvement operations, and stand conversion. The integration of fundamental and developmental research into systems for managing forest properties is the final phase of silvicultural research. Forest managers need to know how various prescriptions for better forest practices fit together into a unified management program. They also need to know how best to modify silvicultural practices to accomodate other forest uses such as watershed, range, and wildlife management and recreation on areas managed for timber production.

USDA and Cooperative Programs

A continuing program of research at all 10 Forest Experiment Stations and the Institute of Tropical Forestry in cooperation with various schools, State forestry groups, private industries, and other private forest landowners is conducted in this field of silviculture. Included is a comprehensive program of basic and applied research in seed production and seed handling, forest nursery practice, site preparation, direct seeding, and planting techniques for important timber species. Studies of natural regeneration and of the care and improvement of existing forests through pruning, thinning, weeding, and other stand improvement measures are carried on in all Experiment Stations.

A long-term program of research comparing different silvicultural systems in different forest types and stand conditions is conducted at many of the Stations to provide practical answers to forest managers. Often these studies are in cooperation with private timber companies who may provide forest land or purchase timber under contracts requiring special treatments and records.

The total Federal effort in silvicultural research in the United States amounts to about 207 man-years annually.

A program of research is also carried on under Public Law 480 in Brazil, Chile, Finland, India, Israel, Poland, and Spain.

Program of the State Agricultural Experiment Stations

The current acceleration of intensive silviculture and forest management depends upon effective results from basic and applied research.

Site studies now in progress are addressed to improve methods of evaluating the productivity of an area of soil for a given tree species (10 projects).

The efficient regeneration of favored timber species continues as the biologic and economic crux of achieving success in forest management. Here research by the states deals with a diversity of subjects. In the even-aged management of conifers making fast growth on good sites, planting is prominent. Other studies deal with stand conversion, direct seeding, natural regeneration, and relative adaptation of certain conifers and hardwoods (19 projects).

Planting studies are represented in the specialized areas of windbreaks and spoil banks (2 projects). Timber stand improvement research includes chemical control of forest weeds, with thinning and pruning also represented in limited tests (8 projects).

Research that is basic to silviculture is considerable in the aggregate and has been grouped in the "soil and water" classification, under II A. There, will be found tree growth responses to fertility and fertilizer, and also research dealing with physiology (especially nutrition) and ecology, phenology, and climatological relationships.

A total of 30 to 35 professional man-years is devoted to research in silviculture.

Progress -- USDA and Cooperative Programs

1. Site Evaluation and Improvement

Techniques for evaluating forest sites for particular tree species when direct measurements on existing trees cannot be used are a continuing need of foresters. Experience has shown that soil factors are the most reliable index, but the particular soil factors that give the best prediction are different for different sites and tree species. Procedures for estimating water oak site index were developed by analysis of data from 135 plots in well-stocked stands throughout the Midsouth by the Southern Forest Experiment Station. About 75 independent variables were evaluated and three methods developed. In Method I, site index is estimated by determining the depth of topsoil, the presence or absence of fragipan, and the amount of exchangeable sodium in the soil. Site index is read from a table computed from a regression equation. In Method II the site is examined for dominant texture, depth to mottling, depth of topsoil, presence of pan, and inherent site moisture condition. Site index is then read from a key. The third method merely requires that the user identify the soil series and moisture phase, and then consult

a table for expected site index range. This method is especially simple to use when a detailed soil map of the area in question is available. For unmapped areas the soil must be identified by a qualified soil scientist.

A similar study of sweetgum site index on wet soils was made by the Northeastern Forest Experiment Station. A soil-factor equation for predicting site index of sweetgum was developed for mature soils of the New Jersey Coastal Plain; the important variables were percent of clay and percent of fine sand in the B_2 horizon, the difference in silt-plus-clay contents between the B_2 and A horizons, and the thickness of the B_2 horizon. Soil series classifications also had diagnostic value, but their value would probably be improved by mapping subsoil thickness and placing more emphasis on fine sand content rather than total sand.

The procedures developed in these two studies will be valuable in reforestation operations in the Northeast and South.

The effects of fertilization and watering were investigated by the Pacific Northwest Forest and Range Experiment Station in eastern Oregon where soil nutrients and moisture appeared to be limiting to tree growth. Ammonium nitrate, treble superphosphate, and supplemental water were applied to 7-year-old ponderosa pine in a windbreak on Deschutes sandy loam. Elemental nitrogen and phosphorus were applied at levels of 0, 200, and 400 pounds per acre in a factorial experiment. Fertilizer treatments were repeated 2 years after initial application. Over a 6-year period after first fertilizer treatment, nitrogen and phosphorus in combination at 200 pounds per acre each stimulated height and diameter growth moderately. Combinations of the two elements including either or both at the rate of 400 pounds per acre led to reduced growth. Tree growth was substantially greater than that of nearby field-planted ponderosa pine of the same age growing under a natural soil moisture regime. Periodic irrigation may have alleviated the greatest limiting factor to ponderosa pine growth in the study area.

2. Artificial Regeneration (Seeding and Planting)

a. Seed production and handling

Accurate estimates of the size of forest tree seed crops are important in planning both artificial and natural regeneration programs. A study in Florida and Georgia showed that seed yields of slash pine can be estimated by means of the regression equation, $Y = 12.7 + 9.31X$, where Y = estimated sound seed per cone and X = number of sound seeds exposed by slicing the cone longitudinally in half. Estimated sound seed yields in pounds per bushel of cones can be made for large, medium, and small seeds and for several different cone sizes. This is a useful technique for estimating slash pine seed crops that may find application in other forest types.

Uniform and complete germination of tree seed over a short period of time is desirable whether the seeds are used in direct seeding or sown in the nursery for producing planting stock. Seed of yellow-poplar (Liriodendron tulipifera L.) normally require 2 or more years for complete germination. A study at the Central States Forest Experiment Station showed that storage of seed for 24 weeks at specified alternating temperatures resulted in germination of all viable seed. The most effective storage temperatures were 36° and 54° F., alternating weekly. Under this treatment, no seed germinated while in storage but it began germinating after 4 weeks in the greenhouse and completed germination 5 weeks later. Warmer storage temperatures caused germination while in storage, and colder temperatures damaged the seed.

Irregular and poor germination of seed is a problem in the regeneration of yellow birch. The Lake States Forest Experiment Station made a study of birch seed stratification by placing four lots of seed under a hardwood stand, one each in November, December, January, and February to simulate the natural periods of seed fall. Germination tests made the following May in the natural environment of a hardwood stand showed that the longer the seed had been stratified, the quicker and more completely it germinated. Germination tests of the same lots conducted in the laboratory under constant temperature did not show differences due to length of stratification in the field. These results show that laboratory germination tests may not reflect differences in germination capacity of seed under field conditions.

Germination of eastern redcedar and black cherry seed can be increased by pretreating with citric acid. The best over-all treatment for eastern redcedar was a 4-day soak in a 10 g./l. solution of citric acid followed by 90 days of stratification at 38° F. This resulted in 93 percent full seed germination at the end of 30 days. The same treatment combination with water replacing the citric acid solution produced 73 percent germination, and the 90-day stratification alone gave 23 percent. For black cherry seed, a 48-hour soak in a 0.1-percent citric acid solution preceding 120 days stratification increased germination from 57 to 89 percent, and the number of days to reach 90 percent of total germination decreased from 22 to 16. Although the mode of action of citric acid has not yet been determined, it can be used to hasten germination of these hard-to-germinate seed.

Sometimes unpredictable events make it inconvenient or impossible to plant seed immediately after they have been given preplanting treatments. Studies in Georgia have shown that seed of the four major southern pines treated with Arasan-75 retained their viability for 60 days at 38° F. under temporary storage conditions. Seed treated with anthraquinone and endrin and stored at 38° F. maintained viability for 1 year. Seed treated with Arasan-75 or anthraquinone-endrin began to lose viability after 20 days when stored at room temperature (70° to 80° F.).

b. Seedling production

Several studies have yielded information contributing to the solution of the ever present problem of producing better seedlings at lower costs both in the nursery and in the field. In the Southeast, 30 amounts and combinations of nitrogen, phosphorus, and potassium fertilizers were applied to slash pine seedlings in sand culture. Height growth and weight were maximum when amounts of nitrogen and potassium were greater than 125 ppm but less than 625 ppm. Maximum responses to phosphorus were not reached at 125 ppm, the highest concentration applied. Studies in Indiana using new pot culture methods showed that infecting yellow-poplar seedlings with endotrophic mycorrhizal fungi improved their growth. Planted black locust and pine improved old-field conditions by causing better soil structure and incorporating mycorrhizal fungi.

Manipulating the photoperiod has made it possible to shorten the time required to grow Honduras slash pine seedlings tall enough to outgrow weed competition when planted in Puerto Rico. An interrupted light period of 11 hours (8 + 3) resulted in tallest seedlings at 7 weeks of age. Controlled environment studies in California showed how day-night temperature combinations, light intensity, and photoperiod interact to control the growth and form of western conifer seedlings. Optimum temperature for seedling growth varied with light intensity, and the effects differed markedly with species. For instance, red fir seedlings increased in basal area with increased light intensity, whereas giant sequoia seedling basal area decreased. The results demonstrate the complexity of environmental factor interaction upon tree seedling growth and the value of determining the effect of individual environmental factors over a range of their natural variation.

In the ponderosa pine forests of the Southwest where growing conditions are severe due to drought and low temperatures during most of the year, the pine seedlings have to send down taproots 1 to 2 feet long during the brief rainy season of July and August in order to survive. A study by the Rocky Mountain Forest and Range Experiment Station showed that the earliest seedlings (emerging before July 22) were five times as heavy and had taproots nearly three times as deep as the latest seedlings (emerging up to August 26) by the time growth stopped in the fall. Differences in size were significant between seedlings that started only one week apart. Date of emergence far overshadowed the minor effect of seed size on seedling size. Root extension was very rapid during the warm days of mid-summer, but very little growth occurred after the first fall frosts early in September. Seeds of ponderosa pine from this geographic source differ from others in that they will not germinate below a sustained temperature of 60° F. This adaptation prevents germination of pine in the Southwest until the characteristic mid-summer rains occur.

A study of ponderosa pine root development in the Black Hills showed that root systems of 1-year-old seedlings grown free of competition were larger than those of 2-year-old seedlings grown where competition was moderate, and larger than those of 3-year-old seedlings grown where competition was heavy. These studies emphasize the importance of site preparation and timing in securing successful natural regeneration.

c. Seeding and planting

A new and improved repellent coating for direct seeding, containing Arasan 42-S, has been developed at Alexandria, Louisiana. It is easier and simpler to apply and more durable than those used previously, and it is well suited for hand seeding operations because it gives off no chemical dust. Arasan 42-S is an aqueous suspension of thiram, the chemical that has been used in powder form as a bird repellent since 1955. Though nontoxic at normal levels of exposure, thiram is a skin irritant, and hence the task of handling seed treated with the dry powder is disagreeable.

Pilot-scale trials, ranging in size from 50 to 600 acres, demonstrated that the new material can be applied rapidly, that seed flow through various types of metering devices is not adversely affected, and that durability under field conditions is superior to that of the powder. While safeguards must be observed in mixing the formulation, the coated seed can be handled at loading sites without discomfort caused by thiram dust. Arasan 42-S is recommended, therefore, to replace both Arasan-75 and sublimed synthetic anthraquinone.

Several studies yielded new information on survival and growth of planted seedlings. Root-pruning in the nursery bed substantially increased field survival of longleaf pine in studies started in Louisiana from 1955 to 1960. Although single and double prunings at several times and at two depths were effective, the preferred treatment was to prune once at a depth of 7 inches in October or November. These seedlings were easier to lift and plant than those receiving other treatments. Pruning sometimes improved survival of loblolly and slash pines but usually had no effect.

The Sandhills in South Carolina and neighboring States are difficult planting sites on which special measures are needed for successful planting. Five-year studies have now shown that on these deep sands, slash pine seedlings survive and grow better if they are planted deeper than they grew in the nursery, but not all the way to the terminal bud. Large seedlings had better over-all survival and height growth than smaller seedlings, but size of stock caused no significant difference in survival when seedlings were planted to the bud.

Moisture content of needles of loblolly and shortleaf pine seedlings can be used to predict seedling mortality before symptomatic needle color appears. There was no clear-cut death point but rather a range, from 65 to 105 percent needle moisture content (dry weight basis), within which a seedling might either live or die. The average survival curve of both species in this critical needle-moisture range indicated 84.7 percent as the midpoint at which a seedling had a 50-50 chance of surviving. Light green foliage was found when the needles contained only 40 percent moisture, which is far below the lower extreme of the lethal range. Yellowish-red needles occurred when moisture content was well below the lethal range, demonstrating that needle color is not a prompt indicator of seedling viability. This information will be particularily useful in deciding whether or not to plant seedlings that have been exposed to drying conditions after lifting.

After five growing seasons, a strip-mine bank planting in Kentucky showed that European alder is beneficial as a nurse crop to other tree species. The alder is a nitrogen-fixing plant and quickly provides shade which retards evaporation of moisture from the soil. In a P. L. 480 study in Finland, alder added from 20 to 80 pounds of nitrogen per acre to the soil through leaf litter, depending on the stand density and site quality. This is equivalent to the nitrogen contained in 400 to 1600 pounds of the ordinary type of commercial fertilizer, a respectable addition to soil fertility.

An effective anti-transpirant could increase planting survival substantially in the arid parts of the West. To date, most materials used have not increased survival, probably because the coating restricted the passage of oxygen and carbon dioxide as well as water vapor. Investigators in an Israeli PL 480 project have found that certain plastic-like coatings are differentially permeable. Water vapor does not pass freely through the coating but the essential oxygen and carbon dioxide do. Water loss of treated plants was reduced but growth was not. The prospects for the development of an effective anti-transpirant appear good.

A summary of the latest available information on tree planting in the central hardwood region was published as Agriculture Handbook No. 247, Forest Service, USDA under the title "Forest Planting Practic in the Central States." It contains detailed instructions on where to plant, what to plant, how to plant, and how to protect the plantations. It will be of value to all who are interested in planting trees in the Central States Area, and especially to extension foresters, farm foresters, forest rangers, consulting foresters, county agricultural agents, soil conservationists and others to whom land owners usually go when seeking advice on tree planting.

3. Natural Regeneration

Successful natural regeneration depends on several factors, among which adequate seedfall is the most unpredictable and least subject to control. In a 10-year study in East Texas, seedfall of shortleaf pine was abundant in only 4 years. In the other 6 years it was negligible. Infrequent seedfall and frequent summer droughts, through which few seedlings survive, have contributed to the deficiency of natural regeneration in this type. Planting must be relied upon to supplement natural regeneration during poor years.

How much expense can be justified in cultural methods to increase loblolly pine stocking is shown in a North Carolina study. On heavy-textured soils, neither burning or disking can be justified. Regeneration and stocking is usually satisfactory following logging by crawler-type tractors and control of hardwoods by frilling. But on light-textured soils burning or disking was necessary to obtain satisfactory stocking, and burning was the cheaper method. Under the conditions of the study, disking was not economically justified. On these soils, too, hardwood control is necessary and justified to obtain free-to-grow seedlings. This study provides land managers in comparable forests with dollar and cents guidelines on the costs of operations and the benefits derived.

Adequate levels of regeneration of lodgepole pine are difficult to obtain. Often reproduction is so thick that thinning is necessary to obtain good growth. Sometimes too few seedlings become established. In a 10-year study of lodgepole pine regeneration on clear cut areas in Montana, most of the seed came from cones in the logging slash. More seedlings came from slash that was piled green than from slash piled after it dried. Seed did not fall beyond 3 chains from the uncut stand in amounts great enough for adequate stocking during 7 to 10 years of observation. These findings have provided a tentative basis for regeneration practices in this type in central Montana. In eastern Oregon, however, the cones are not serotinous but open on the tree. Here seed was distributed from the edge of the timber for such a short distance that cutting areas probably should be no more than 400 feet wide.

Natural regeneration of longleaf pine is complicated by the short distance of seedfall. In a study in Alabama about three-fourths of the seed fall within a chain of the seed trees. However, competition from overstory trees, as in a shelterwood system or scattered seed trees, was not so severe as to drastically reduce survival. In a stand with 90 square feet of basal area, 80 percent of the seedlings survived after 7 years and stocking was very high. Although the overstory suppressed growth, brown spot infection was lower with an overstory than in open areas. From these data one can infer that a seed-tree or shelterwood system favors the successful establishment of natural reproduction of longleaf pine.

4. Silvicultural Systems

Research in all sections of the country is adding to our knowledge of the best harvesting methods to produce the desired new stands of trees and to meet the many requirements of multiple use forestry.

In the mixed conifer swamp forests of the Lake States region, a study of several even-aged and uneven-aged methods was made to learn the best way of getting a high proportion of desirable conifers in the new stand. Clear cutting in small blocks or narrow strips proved to be the best method, while partial cutting methods were poorest. All cutting methods encouraged the invasion of hardwoods to some extent, and control methods should be used to obtain full stocking and rapid juvenile growth of desirable conifers.

Old-growth ponderosa pine forests of the Southwest have been under study for over 50 years. During this time they have been partially harvested by group selection, improvement selection, and salvage cutting. During this period these stands have shown a gradual shift to smaller and younger trees, reduced board-foot growth, and increased cubic-foot growth. A recommended conversion procedure for virgin ponderosa pine stands emerging from this long study is to (1) remove the old growth in two or three cuts and where necessary thin young sawtimber groups, (2) thin young pole and sapling stands as early as possible, (3) plant nonstocked areas where satisfactory natural regeneration appears only at irregular intervals, and (4) after the second or third partial harvest cut, make a final harvest cut to produce an even-aged new stand.

A detailed study of cost of logging was made in old-growth redwood by the Pacific Southwest Forest and Range Experiment Station. The costs of logging and road development were computed for shelterwood, selection, and clear cutting operations. Costs were highest on shelterwood and were lowest and about equal on selection and clear cuttings; higher costs were due to smaller sized trees and logs. This study also produced equations to predict daily felling and bucking production by a 2-man crew based on average d. b. h. of trees, and tractor skidding and mechanical loader production based on average log volume. These equations will permit a computation of logging costs under changing wage conditions.

Research results are adding to the knowledge of managing the small forest property so common to the eastern United States. An example of the financial returns from forest land in Alabama was reported where timber worth more than $5,700 has been harvested from a 40-acre tract of longleaf pine that has been under management since 1947. The products, including poles, sawtimber, pulpwood, dogwood, gum, fuelwood, and posts, have had an annual average value of $3.99 per acre when sold on the stump, or $9.03 delivered to market. There is more and better timber on the area now than when cutting began; the sawtimber stand increased from 1,774 board feet (Doyle rule) per acre in 1947 to 2,474 board feet per acre in 1962, and an average of 1,425 board feet per acre was cut in the meantime. The 1963 harvest was 23 poles, 1,854 board feet of sawlogs, and 5 cords of pulpwood--worth $154 as stumpage or $317 delivered to market. These results from 16 years of good management show that similar tracts can provide a modest but steady revenue while they are being improved.

A study of harvesting mature loblolly pine on the Eastern Shore of Maryland showed that preconditioning the stand by prescribed winter burning followed by a seed-tree cutting resulted in very good natural regeneration. Burning greatly reduces the number of small hardwoods; ones larger than 3 inches d. b. h. may have to be poisoned. Sometimes a preparatory cut to remove pulpwood-size pine before the seed-tree cut will further reduce understory hardwoods and salvage many trees that otherwise would be lost by natural mortality or by breakage during the main cutting. These treatments should ensure a new stand of 85 to 90 percent pine and prove to be economically and silviculturally desirable on the Eastern Shore.

To assist in the management of Appalachian hardwoods a study was made of cull tree removal following partial cutting. It was concluded that culls above 11 inches d. b. h. should be deadened at the time of logging and smaller culls left for about five years to allow many of them to die of natural causes. It was shown that once these hardwood stands are cut selectively and the cull undesirable trees killed, the development of new culls is very slow and subsequent cull removal is a small task.

5. Stand Improvement

a. Thinning

Thinning of young stands not only affects radial growth at breast height but also affects radial growth all along the stem. Studies in ponderosa pine in the Black Hills have characterized these changes in both stagnated and non-stagnated stands. Before thinning, the annual layers were widest at about 80 to 85 percent of tree height and narrowest at 20 to 25 percent of tree height. During the period of most rapid growth following thinning of stagnated stands, the annual layers were widest at the tree bases and narrowest at about 70 percent of tree height. This change in growth pattern resulted in greatly increased taper. After the period of maximum radial growth, the annual layers were again widest at about 85 percent of tree height and narrowest at about 25 percent of tree height. Thinning an overstocked but not stagnated stand did not change the pattern of vertical distribution of annual increment, bole form, taper, or ratios of height to diameter. These findings will be useful in interpreting radial breast height growth of thinned stands as well as providing confirmation to theories of bole development.

Growth of ponderosa pine in dense young stands in California is also often poor. Some of these young stands were thinned to reduce the number of trees competing for scanty soil moisture. After 5 years, residuals at 9 x 9 foot spacing had grown 3 times as fast in diameter and 67 percent faster in height than trees on an unthinned area. Some definite information on predicted increases in growth in stagnated stands is now available to forest managers, private and public, in this important timber area.

By dividing his woodland into annual thinning units, a small woodland owner can produce annual income and, at the same time, the potential growth of the land can be maintained or even increased. Annual return, as well as increased production of high-quality timber, is being demonstrated as commercially feasible in a 42-year-old 40-acre western Washington woodland. During the first 13 years, a stumpage value of $3,384 was obtained while adding $4,028 to the value of the starting volume through increased growth. After allowance for annual management and thinning costs, a total net return of $5,320 was realized from the tract. Thinning timed less frequently and toward securing more favorable market opportunities would have been even more profitable. Implications of this example will be of value to the 53,000 small woodland owners (under 100 acres) of the Douglas-fir region.

Conventional thinnings, removing scattered stems, are not very practicable in loblolly pine plantations which were commonly started at 6 x 6 foot spacings on Maryland's Eastern Shore. Cutting all the trees in selected rows would bypass the difficulties of conventional thinning. Recently, four intensities of row-thinning (cutting every second, third, fourth, or fifth row) were compared. Cutting every third row proved to be the best prescription for initial thinning in terms of residual stocking in crop trees and increases in diameter growth. It also favored greater crown ratios, and increased stand volume growth by 12 percent, as compared to an unthinned control. Eastern Shore landowners now have a practical method for initial thinnings of loblolly pine plantations.

Thinning prescriptions have been developed for improving stand quality in a number of hardwood types. Recent research has indicated that thinnings and other stand improvement methods should be valuable in reducing the incidence of gum spot, a serious defect in black cherry logs caused mainly by the Prunus miner whose larvae reach the main stem through the major branches. Suggestions for silvicultural control include: cultural treatments such as early weedings and stand-improvement thinnings in young stands, removal of large rough dominants of sprout origin from older stands, and development of new stands of black cherry in dense groups on sites below the zone of severe glaze damage. These recommendations should yield higher future stumpage values for Allegheny Plateau black cherry to landowners who adopt them.

Contrary to previously published reports, preliminary results demonstrated that Virginia pine older than 10 years can respond to release. One year's diameter growth of dominant, codominant, and intermediate trees in the 10-14, 15-19, 20-24, and 25-29 age classes is significantly greater after release than growth of paired control trees. Release consisted of removal of all competing trees around the study tree in a circle with a radius 35 percent of the average dominant height for the age class. These results provided the impetus for establishing growing space studies of Virginia pine to obtain more precise information on its response to a larger growing space.

b. Pruning

In some species of oaks, new branches frequently form on pruned boles, and if persistent, they reduce the benefits occasioned by the pruning. After screening a number of chemicals sprayed on the pruned bole of white oak, it was found that SAE-20W motor oil killed practically all suppressed buds capable of forming new branches and yet rarely injured the trees. This research opens new approaches to prevention of branch formation on valuable portions of the bole through chemical means.

The costs of cultural operations in the forest are assuming increasing importance. Methods for estimating these costs were developed for pruning shortleaf pine, loblolly pine, and pin oak. For the pines, pruning time can be estimated quite accurately for various stand conditions based on the total number of trees, their size, and the size of the trees pruned. For pin oak, with a profusion of branches, pruning time is a function of the number of branches. These predicting mechanisms provide another tool for forest management decision making.

c. Herbicides for killing unwanted woody plants

New prescriptions have been developed which permit the use of cheaper chemicals in tree injectors and extend their use throughout much of the eastern United States. Large reductions in costs are in prospect through the use of undiluted 2,4-D amine--a low cost chemical--instead of diluted 2,4,5-T ester. Studies in the South show that 2,4-D is the practical choice because it costs about $2.75 per gallon as against $7.00 or more for 2,4,5-T. In the Lake States, a new systemic herbicide (4-amino-3,5,6- trichloropicolinic acid) is also proving more effective in injections than the

standard 2, 4, 5-T. Recent injector trials in the Middle Atlantic Coastal Plain have confirmed the utility of tree injectors in that region. Although undiluted formulations have not proven as successful as in the South so far, tree injector recommendations for the use of both ester and amine forms of 2, 4, 5-T have been released. Many of these results are already in practical application with lowered production costs for the timber producer.

For mass control of small sterms, mistblowers give cheap, effective control where methods have been worked out for the species involved and for specific objectives. Two advances in the use of mistblowers were recently made. In Maine, it was found that undesirable hardwood understory growth in young paper birch stands was satisfactorily reduced with 1/2 pound acid equivalent of 2, 4, 5-T per acre in invert emulsion without damage to young overstory paper birch. In the Middle Atlantic Coastal Plain, it was found that mistblower applications of 2, 4, 5-T can be used advantageously in regenerating preferred species. In some stands their role would be in the selective release of conifers; in others it would be in preparing sites for the establishment of desirable reproduction.

A herbicidal treatment must not only kill unwanted vegetation to be effective, but it must also meet the landowner's objective. One common objective is rapid acceleration of growth on the released crop trees. Five-year results of a yellow-poplar seedling release study in southern Indiana indicate that released trees were three times as tall as those not released. Failure promptly to release planted shortleaf pine on the Cumberland Plateau sacrificed about 1 year's growth for each year of suppression. Under favorable or average conditions, most seedlings survived for 2 years without release, but survival as well as growth can be reduced in drought years. But in the New Jersey Plains region, release of pitch pine sprouts originating from old stools is ineffective. Herbicidal control of weed tree sprout clumps competing with the pitch pine sprouts did not increase the height growth and, after six years, there is little promise that these stems will develop into crop trees. Suggested alternative methods of increasing the growth of these areas include non-selective mistblower treatments which would also kill the pitch pine stools, followed by prescribed burning and seedling regeneration methods as dictated by residual seed source.

6. Animal Damage

The terpene constituents of pines and their hybrids may determine in part the susceptibility of trees to damage by mice. In a pine plantation in Massachusetts girdling by mice varied appreciably among the species. Some species were severely damaged, others lightly or not at all. Hybrids between those with severe damage and those with little or none were intermediate in incidence of damage. Among the species studied, the higher the amount of alpha pinene in the turpentine, the higher the proportion of trees damaged.

The success of direct seeding often depends on the number of rodents inhabiting the area. A study of small rodent populations in Texas showed that there were as many as 2.5 rodents per acre on forest land and 4.0 per acre on open land. Each rodent ate about a gram of pine seed daily. This population would consume most of the seed applied in direct seeding attempts, about one pound per acre. Without control of the rodents by repellents or other means, direct seeding attempts will fail when populations are this high.

Direct seeding of oaks and other larger seeded species usually fails because of rodent pilferage. In a South Carolina study acorns treated with an arasan-endrin mixture were not taken by either cotton rats or gray squirrels when untreated acorns were available. But when only the treated acorns were available, the squirrels took the acorns although the rats still refused them. More effective treatment must be sought to protect the seed from squirrels when alternative food supplies are low.

Animal damage is becoming increasingly serious in many forest regions, particularly in the Pacific Northwest. To isolate the most important problems and to establish a starting point for attack on these problems, scientists in the Pacific Northwest Forest and Range Experiment Station have prepared a comprehensive review of animal damage and progress in controlling it. The study indicates that contact toxicants and repellents are at best only stop-gap measures and that systemics, and perhaps cultural methods, offer the best solution.

7. Shelterbelts

A comprehensive handbook on tree windbreaks of the Great Plains was published this past year as a USDA Agricultural Handbook by the Rocky Mountain Forest and Range Experiment Station. Primarily for technicians, this handbook deals with the details of establishing shelterbelts as well as their effects on local climate and crops. Land preparation, species selection, planting, maintenance, and protection are all covered rather completely. This publication brings together information from years of shelterbelt research and will be a valuable handbook for technicians throughout the Great Plains.

Another aid to shelterbelt growers is a set of growth curves for Austrian pine developed by the Rocky Mountain Forest and Range Experiment Station. These curves show the tree heights that can be expected at ages up to 50 years after planting. They also can be used as site index curves by which the quality of a site can be evaluated from the height that Austrian pines attain at age 20.

For several years a leaf blight of undetermined origin has appeared on boxelder (Acer negundo L.) and occasionally on several other tree species of the Northern Great Plains. Growth loss and unsightly appearance have resulted in a decrease in the use of boxelder as a shelterbelt species. Several factors associated the blight with damage by 2,4-D--a herbicide used extensively in this region as an aerial and ground crop spray. A study involving the use of indicator plants sensitive to 2,4-D, root repression tests, and chromatographic analysis of blighted foliage was undertaken to test this hypothesis. Results of all tests indicate that 2,4-D is the cause of the blight. This knowledge will lead to measures of protection.

8. Growth Requirements for Forest Trees

The commercial importance of stem form is readily accepted by practicing foresters but few of them are aware of the relationships between form and conditions of growth and the biological causes of variation in form. Several summary publications during the past year synthesized research results concerning stem form into general working principles. For example, as a general rule, the longer and more vigorous the crown, the greater the stem cylindricity. In terms of forestry practice, any factor favoring crown development will tend to increase stem taper, and any factor hindering crown development will tend to increase stem cylindricity. Knowledge of biological principles such as developed in these papers can be used effectively by practicing foresters in their daily operations.

In any form of applied ecology, but especially in plant introduction trials, a knowledge of weather and climate can save much wasted time, effort, and money. The Luquillo Mountains in Puerto Rico support the only tropical rainforest within the National Forest system, and one of the most intensively studied rainforests anywhere. Its weather patterns were recently summarized. Similar summaries of climatological measurements have also been published for the central Sierra Nevada of California, where sites are suitable for a number of different species and hybrids.

East of the prairies of the Red River Valley the bed of former Glacial Lake Agassiz is blanketed by vast and nearly continuous peatlands. Recent intensive studies have shown that these peatlands support a great range of forest sites and timber types or plant communities. A type of "patterned bog" which is characteristically found within or near the Arctic Circle was discovered in the Minnesota peatlands. Other studies indicated that bog expansion with subsequent site deterioration is continuing, contrary to previously accepted theories of forest succession. These studies have provided methods for recognizing and delineating peatland site capabilities.

The cold wave that swept through the Pacific Northwest Forest and Range Experiment Station in November 1955 killed large numbers of native forest trees, and countless others were damaged but survived. Detailed growth measurements taken on 50-year-old codominant Douglas-fir trees which appeared to be only moderately damaged shed light on further consequences of the freeze injury. Radial growth in 1956 averaged 51 percent of the 1954-55 rate. Growth rate then improved quite regularly through 1959 when it reached about 87 percent of the 1954-55 rate. Trees growing most rapidly prior to the freeze tended to suffer the greatest reductions, but also made the best recovery. Height growth and branch elongation were similarly curtailed. These results stress the importance of knowing climatic conditions before using past growth records for prediction purposes.

The Pacific Northwest Forest and Range Experiment Station has recently completed studies on the life zones and major plant communities in the Cascade Range so that the true fir-hemlock forests can now be delineated. Initial stratifications of forest stands have been made in the northern Washington Cascades, and climax species in each life zone and important understory species in each community have been determined. The true fir-hemlock forests of the Pacific Northwest mountains have been

separated into subdivisions based on physiographic provinces. These subdivisions are correlated with major differences in geology, climate, soils, topography, and vegetation. Research results in these forests can now be related to definite areas of application.

Interest in noble fir is increasing rapidly with the expanding utilization and management of higher-elevation forests. Ecological studies now show that, in the Cascade Range, the northern limit of noble fir is apparently near Stevens Pass, Washington (Latitude 47° 45' N), where it is thriving. It probably does not occur in the Olympics. The status of noble fir in southern Oregon will remain in doubt until the relationships between California and Shasta red fir and noble fir are clarified. Pure stands of noble fir occur with regularity and the species appear to be more tolerant than previously supposed. Available data indicates yields of noble fir stands can be very high, near 300,000 board feet per acre for the best old-growth stands.

Many silvicultural practices depend on a knowledge of the stage of dormancy or activity of the tree. Basic research aimed at understanding the control of dormancy and growth in trees was aided substantially by an analytical review of the world's literature on the subject. Published as a USDA Technical Bulletin, this review brings together knowledge of the mechanisms controlling tree growth, points out areas where knowledge is weak, and indicates profitable lines of research. It has been hailed by scientists in many parts of the world as an outstanding contribution to forestry and botanical research.

Basic research is helping explain some of the observed differences in growth rate among forest tree species. In a North Carolina study comparing white pine and loblolly pine, the rate of photosynthesis was found to reach a peak in mid-July for white pine but not until mid-September for loblolly pine. The respiration rate of white pine peaked in May and then remained steady while that of loblolly pine continued to rise. The rate of growth of white pine also reached a peak in May while that of loblolly was later. Studies such as this provide an understanding of some of the adaptive mechanisms which make it possible for various trees to compete in particular environments.

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B. FOREST MENSURATION

Problem

Intensive management of the forest types of the United States requires improved measurements of timber tree volumes and more reliable predictions of future growth, yield, and quality of forest products. Productivity of forests both in quality and quantity varies markedly according to stand density, site quality, tree age, and species composition. Optimum stand conditions for particular management objectives need to be determined for the many combinations of timber types, sites, and conditions found in American forests. Important forest reguation problems involving levels of growing stock, cutting budgets, and rotation lengths much be solved to guide wise management of large timber holdings.

USDA and Cooperative Programs

A continuing program of studies is conducted at all the Stations, often in cooperation with industries, other private landowners, State forestry agencies, and forestry schools. Special attention is being given to research in the growth and yield of managed forests, juvenile forest stands, and forest plantations. Research is also concerned with mathematical techniques and forestry measurement tools that will make for greater precision and efficiency in practical forest management operations and in forest research. A pioneering research unit in Berkeley, California, established in 1961 is studying basic mensurational problems. Nationwide, 8 man-years of Federal scientific effort are performed in formal mensuration research projects, and about 6 additional are devoted to related growth and yield studies in silviculture projects and reported thereunder.

Program of the State Agricultural Experiment Stations

Forest management research including forest inventories, stand sampling, and timber scaling comprises a diversity of studies in experiment stations of a number of states. Farm forest growth and yield, efficiency and profitability of alternative practices for improving stands and operational control techniques are under study in 16 projects.

There are several volume table, growth and yield studies dealing with hardwoods as well as conifers.

One study is devoted to aerial photogrammetry and forest measurements.

Total, 19.6 professional man-years.

Progress -- USDA and Cooperative Programs

1. Growth and Yield of Forest Trees and Stands

Reliable growth and yield predictions are fundamental to forest management planning, but until recently American foresters have had to rely mainly on normal yield tables that are notoriously inadequate, particularly for managed forests. Actual data from repeated measurements of permanent growth plots are required for accurate information, but they are slow and expensive to obtain. A recent publication by the Pacific Northwest Forest and Range Experiment Station summarizes growth and yield data from 31 Douglas-fir plots, some of which have continuous records since 1909. These actual growth measurements extending over a 50-year period are very valuable for many direct uses in addition to checking out the accuracy of the normal yield tables. The data from these plots show that the normal yield tables, originally published in USDA Bulletin No. 201, are generally accurate within their inherent limitations. Other valuable mensurational and silvicultural information also has been obtained from these old growth plots, and we can expect increasingly important data as these plots are maintained and measured in the future.

Gross and net yield tables also have been developed for lodgepole pine in a detailed study of felled and sectioned trees. The gross yield tables, particularly, are a valuable addition to the knowledge of lodgepole pine growth and yield, because they present a unique approach to estimating yields from intensively managed stands. For example, this study revealed that gross yields of 70 cubic feet per acre per year were being produced by lodgepole pine stands on average sites during their most productive period. This is about 45 percent greater than net yields obtained without intermediate management.

Actual performance of forest stands under systems of periodic thinning and other cultural measures produce valuable data to guide future management planning. A study at the Lake States Forest Experiment Station in red pine was reported in which three stand densities on each of two site classes were evaluated over a range of stand ages from 35 to 165 years. Based on the results of this study, projections were made which showed the size and numbers of trees per acre that can be expected on various sites in the future. For example, these projections indicate that at a rotation age of 105 years, average diameters will range from 10 to 22 inches on good sites, depending upon the stand density maintained, and the numbers of trees per acre will vary from 33 at low density on a good site to 335 at high density on a poor site. Such information is highly valuable to a forest manager.

The same study in red pine emphasizes the great differences in final production both in size and quality of product due to site quality. Total volume, for example, can be three times as great at age 100 on a good site (index 75) as on a poor site (index 40). Site quality was shown to be more important to final yield than either stand density or rotation length. This study emphasized the benefits of concentrating timber-growing investments on high-quality sites.

Growth predicting is complex in uneven-aged stands, particularly when the distribution of diameter classes is not typical or regular. Stand projection techniques are generally used, and the concept of "q", the average quotient between numbers of trees in successively smaller d.b.h. classes, has proven to be a useful expression of diameter distribution for balanced uneven-aged stands. A similar expression was needed for the irregular or unbalanced stands that are so common in the Northeast. For a wide variety of northern hardwood stands, the quotients between numbers of trees in successive 4-inch d.b.h. classes were found to be linearly related to dbh; thus, the diameter distributions for a variety of stands could be represented by the slope and intercept of this linear relationship. The results provide some basis for further research into the growth, yield, and regulation of unbalanced, uneven-aged stands.

A group of over 100 plots in loblolly pine stands located in Georgia, South Carolina, and Virginia has been under intensive management and study for over ten years. Representing a range in site, stand density, and age, these plots have yielded valuable information for models in cubic-foot and board-foot growth that have been reported in past years. Using these same data, another analysis completed last year gives a growth equation for basal area of managed stands. It shows that 5-year basal area growth is a function of stand density, density-age, and density-site interactions,

and is described by a curvilinear form in relation to stand density and age. It culminates at a considerably higher stocking level on good sites than on poor sites. This growth model will be a valuable addition to our growing information on the performance of managed forest stands.

Stand density, age, site, and various combinations and powers of these three variables are usually the most important for expressing growth and yield, but undefined variation always is present. The data from the loblolly pine managed growth plots, discussed above, were again used to evaluate another variable, diameter distribution. The effects of 15 expressions of diameter distribution on merchantable cubic-foot growth were evaluated, but none was found to have an appreciable influence on growth. The conclusion reached as a result of this analysis was that the probability of reducing unexplained variation in merchantable cubic-foot growth in managed, even-aged loblolly pine with characterizations of diameter distribution is small. These results, though negative, are valuable additions to the growing store of knowledge on factors affecting forest growth.

A third study, employing data from the loblolly pine plots, developed models to express realistically the relationship between growth and yield. Selected yield models previously used were differentiated with respect to age to produce models for cubic-foot and basal area growth. These growth models and selected yield models were then fitted to data from the 5- and 10-year remeasurements of the loblolly pine plots. Resulting equations can be used to predict total per-acre production for various rotation ages and thinning regimes.

A Forest Science monograph was published this year from the mensuration Pioneering Research Unit dealing with the problems of more accurate tree measurement. This publication presents a unified picture of the geometric principles involved in the three types of optical dendrometers used for accurate measurement of the upper diameters of standing trees. The monograph develops new and exact theory for range-finder dendrometers, and translates this theory into a high-speed computer program for converting instrument readings into tree volume and supplementary information.

The tree measurement research was extended to developing a complete program for sample tree measurement for use in timber sales and for other inventory purposes. The details of this system are contained in two publications; one describes a new sampling theory and the other is a detailed computer program for translating the measurements from sample trees directly into timber volumes and other statistics required by the forest manager. Detailed field evaluation is now underway for this revolutionary method of timber inventory.

2. Forest Measurements

Customary methods of site classification based on total age and tree height are difficult to apply to tolerant species such as grand fir. Juvenile growth rates are frequently very irregular, so that total age often includes substantial periods of slow growth due to overstory competition. Procedures described in a publication

from the Intermountain Forest and Range Experiment Station define site index in terms of the periodic annual height increment attainable by trees at a standard height of 55 feet. Data used to determine site index as defined are height, age, and initial diameter growth rate. By eliminating the effects of factors that affect the tree only during the seedling and sapling stages of development, this technique should estimate a site index that closely corresponds to periodic stand increment.

Grand fir is one of the preferred species for pulping in the Inland Empire, and, accordingly, the most logical unit of measure is the weight of dry fiber in the tree bole. The prediction equations presented in a paper from the Intermountain Forest and Range Experiment Station provide a means of estimating the dry weight of the tree bole from height, diameter, crown class, and specific gravity of increment core samples at breast height. In addition, similar prediction equations were derived for specific gravity of the tree bole, and for the outer 20 annual layers of wood on the bole. These equations will greatly increase the efficiency of cruising pulpwood timber.

Index curves for evaluating site quality on the basis of tree height and age are a standard tool of foresters, and techniques of constructing these curves are often inadequate to reflect the detailed growth patterns from site to site. Cutting and sectioning trees to obtain past diameter and heights for constructing site curves is the most accurate method known, but the collection of field data is costly and analytical methods cumbersome. The Pacific Northwest Forest and Range Experiment Station has developed a simple, direct, and statistically sound analytical method, combining graphic and regression techniques, for estimating site index from sectioned tree stem data, based on experience with red alder trees in western Washington. This method will be helpful to many others engaged in this type of analysis.

The Rocky Mountain Forest and Range Experiment Station published several volume, taper, and point-sampling tables for use in measuring ponderosa pine trees and stands in the Southwest and Black Hills. These tables are essential working tools in conventional cruising, point sampling, and assigning volumes to specific products and quality grades.

The cost of scaling all the logs in a timber sale sometimes is excessive and out of proportion to the value of the logs. In a study conducted by the Pacific Northwest Forest and Range Experiment Station in coastal Oregon it was found that scaling a randomly selected sample of truckloads not only amounted to considerable savings but resulted in highly acceptable accuracy standards when compared with total scaling. A second sampling method that involved weighing all loads and converting weight to board-foot scale by a converting factor determined from a sample scale proved to be slightly more accurate, but also more costly, than straight sample scaling. Techniques for using the two sampling methods are described in a Journal of Forestry paper and should be widely applicable.

3. Management and Planning

Detailed planning of long-term timber management on forests with irregular distribution of age classes, multiple products, diverse sites, and many other related variables becomes difficult if not impossible by conventional means. Usually strict limitations are imposed such as sustained and even yield, maximum production, and compatability with other forest uses. A promising mathematical approach to a solution of such problems is discussed in a publication by the Northeastern Forest Experiment Station. The process is called linear programming, and results of two simple, hypothetical examples are presented to demonstrate how the estimation of maximum allowable yields from unbalanced, even-aged forests can be made. This technique has great promise of being valuable to forest managers as the details are further refined and input data are made available.

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C. FOREST GENETICS

Problem

The development of artificial reforestation programs in the United States has set the stage for a tree improvement program of major proportions. Basic facts are needed concerning natural variation in forest trees and the heritability of characteristics that have biological or economic value. Strains or hybrids of timber trees having rapid growth, high quality, and superior pest resistance must be developed as soon as feasible. Speeding the development of trees that are resistant to insects, diseases, and other pests has special urgency because it will reduce the use of chemical pesticides with their attendant hazards.

USDA and Cooperative Programs

A continuing, long-time program of basic and applied research involving the whole field of genetics as applied to forest trees, from cytogenetics to phenotypic selection and progeny testing, is underway. The program involves the study of variability within species with respect to growth rate, form, and adaptability to environment as a basis for superior tree selection. It is concerned with the heritability of characters such as disease and insect resistance, drought and cold resistance, wood quality factors, vigor, and other important morphological, physiological, and anatomical characters. Other aspects of the project include the investigation of crossability of various species, aimed breeding for specific characters, radiation-induced mutations, and factors affecting fertilization and flower induction. Basic genetic processes are investigated through cytogenetic studies of tree species. Also included is research on the identification, classification and distribution of species and hybrids of forest trees.

The program is carried on principally at three Institutes of Forest Genetics located at Placerville, California; Gulfport, Mississippi; and Rhinelander, Wisconsin; with additional work in Oregon, Idaho, Illinois, Vermont, Pennsylvania, Georgia, Florida, and Louisiana, involving cooperative research with numerous State agencies, private foundations, universities, and forest industries. In addition, research grants for basic research in genetics under the provisions of Public Law 480 are in force in Finland, Israel, India, Chile, and Brazil. The annual Federal scientific effort directed to this research by the Forest Service is about 29 man-years.

Program of the State Agricultural Experiment Stations

Forest genetics and tree improvement projects at the state stations include some of the largest and longest established programs in this field. There are 29 projects, of which 23 participate in Regional Research projects in the Southern, Northeastern and North Central regions. Variation in form, growth, wood properties and resistance, including intensive cooperative studies of seed source, accounts for two-thirds of the total program. Other investigations are concerned with hybridization, breeding techniques and systems, and basic genetic understanding. Coniferous species receive major attention, but the number of projects dealing with hardwoods show substantial recent increase.

Total, 29.2 professional man-years.

Progress -- USDA and Cooperative Programs

1. Hybridization

Reconnaissance breeding among the southern pines has helped to clarify the relationships in this group and to demonstrate that breeding attempts outside the group probably will not be successful. Eight of the 10 southern pines can be crossed readily with most others, but some crosses appear incompatible. Also crosses between the southern pines and western pines, which would be desirable from the standpoint of introducing pest resistance factors, appear to be improbable. Among the easily-crossed southern pines, natural hybridization is usually prevented by location differences or by differences in time of flowering. Incompatibilities resulting in aborted cones and inviable seed or seedlings prevent other crosses from being successful. This type of reconnaissance breeding provides guidelines within which geneticists can produce improved trees.

European aspen may provide valuable germ plasm for hybrids with quaking aspen. In a screening study of sources of aspen from Europe, selections from middle and southern latitudes crossed with quaking aspen from east-central North America produced vigorous hybrids suited for planting in the Northeast, Lake States, and adjacent Canada. Because of its habit of reproducing by root suckers, such hybrids of aspen could be maintained vegetatively under management practices and save future breeding costs.

The reclamation of strip-mined land is being speeded by hybrid poplars which have grown well on some sites on the spoil banks. In a screening study in Pennsylvania and West Virginia, of 60 different clones planted on spoil banks, the best hybrid grew 7 feet in 2 years. Survival and growth were poor on the very acid spoil banks, however. Special care in selecting planting sites must be exercised in order to take advantage of the growth potential of the hybrid poplars.

Out of 50 hybrid poplar clones planted on two kinds of graded spoil banks in Harrison County, Ohio, more than a dozen have survived and grown well. The American eastern cottonwood, the European black poplar cultivars "Charkowiensis" and "Caudina", and Populus maximowiczii from east Asia were among the parents producing the best hybrids.

Tree improvement in many of the hardwoods has been hampered by the difficulty of rooting certain species, particularly oaks. By refinement of techniques, such as the use of distilled water in mist-chambers, both air layers and cuttings of several oaks and other species have been rooted. These new procedures now make it possible to produce clonal lines of trees selected for desirable characteristics and should hasten the breeding of improved hardwoods.

Yellow-poplar is another important tree species generally considered difficult to root, and even more difficult to establish successfully from rooted stem cuttings. A method has now been found to propagate yellow-poplar successfully by using stump sprouts, rather than branch cuttings from intact trees. Cuttings from these sprouts can be used as clonal material in studies dealing with site requirements, nutrition, and physiology where control of genetic variability is desirable.

The ease with which cuttings from trees can be rooted has often been observed to vary among trees of the same species. A Korean PL 480 project is aimed at determining the nature of the differences and whether the observed differences are hereditary. Results so far give statistical proof that differences do exist and that extracts from easy-to-root cuttings from both pine and poplar have a higher carbon-nitrogen ratio than from hard-to-root cuttings. Research is underway to determine the nature of the chemical compounds which are excessive or deficient in the cuttings and the degree to which the tendency to root easily is inherited.

Progress in forest genetics is also hampered by the difficulty of propagating pines vegetatively. A technique for large-scale multiplication through needle fascicles would be particularly helpful. In a PL 480 project in Chile, needle bundles from trees up to 8 years old, which were producing seed, were rooted by means of an indole-butyric acid treatment. In addition moderate success was obtained in stimulating shoot growth of the bundles with the growth substance, kinetin. Research is underway to clarify the role of day length in the development of the shoots and to find out how to stimulate the development of roots and shoots on fascicles from older trees.

Induction of early flowering of some species is still a critical problem in forest genetics research and seed orchard management. In a series of studies in Idaho to induce flowering, grafting of scions from young seedlings on trees of bearing age did not stimulate the scions to produce cones. Various combinations of cultural treatments, watering, cultivation, and fertilizing, were applied to trees 11 years old to stimulate flowering but none were successful. Finally, trees of cone-bearing age were fertilized to increase cone production. There was no increase although such treatment has increased cone production in other studies. The results of these

studies seem to bear out the hypothesis that forest trees must pass through a certain transition from a juvenile to a mature stage and that this may be accomplished only by attainment of a certain size or age. The studies do emphasize the difficulty of increasing or inducing cone production, an extremely critical phase of tree improvement programs.

Barriers to crossing even between species which are considered to be closely related hinder the efforts of tree breeders. To understand the cause for these barriers, a P. L. 480 project in Finland is concerned with development of the pollen grain and subsequent fertilization. Two general types of incompatibilities occur. In one, the pollen grain never germinates for some as yet unknown reason. In the other, the pollen grain germinates, the ovule is fertilized, but then the cell fails to divide or differentiate. In both cases the cone aborts. Research is continuing in an attempt to determine the underlying causes of these incompatibilities.

The extent to which pollen mixing occurs in forest stands is a key factor in the development of seed orchards. In some species inbreeding, as might occur among members of the same clone in a seed orchard, produces progeny with depressed growth rate. In a P. L. 480 project in Finland, radioactive phosphorus was injected in trees just before pollen was mature and the developing pollen accumulated the phosphorus.

Collecting slides were placed in the stand to sample the pollen. Radioactive pollen was detected throughout the stand, showing that there was widespread pollen mixing.

2. Variation

Regeneration of longleaf pine is hindered by the brown spot disease. A high degree of resistance to this disease has been found in some longleaf pine seedlings in Louisiana. These were the progenies of a tree which was found as a disease-free seedling in 1937. Seedlings from wind-pollinated seed from this tree had only about 10 percent of infected foliage compared to about 50 percent infection in ordinary stock. The observations indicate genetic control of the resistance to brown spot in longleaf pine seedlings and provide hope that further selections for resistance will be successful.

Most of the degrade in white oak is caused by knots. Studies in Illinois have shown that the number of branches and undeveloped buds on the butt log varies widely but is relatively independent of growing conditions. Since these characteristics appear to be under genetic control, it should be possible to select and breed for trees with a minimum of knots and thereby improve the quality of white oak.

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D. TIMBER-RELATED CROPS

Problem

In addition to the five major products and services of the forest (timber, forage, water, wildlife, and recreation) there are a number of timber-related forest crops, some of which are sources of important industries in different parts of the country. These products include naval stores, maple sap, Christmas trees, and a group of minor crops composed of edible, medicinal, and decorative materials. Some of these crops when integrated with timber production greatly enhance the total income of forest owners. These crops also provide a ready cash income which is not easily obtainable from periodic timber harvests. Many of the minor forest crops provide supplemental income to individuals in low-income areas and also provide opportunities for new industries. The research problem is to determine the potentialities of these timber-related forest crops and to develop the most efficient methods for their production.

USDA and Cooperative Programs

The present program of Forest Service research in timber-related crops includes a project in naval stores production and related tree improvement research at Olustee, Florida, a project in the production of maple products and related tree improvement research at Burlington, Vermont, and a small amount of research on Christmas tree production conducted as part of silvicultural and genetics projects in Michigan, California, and elsewhere.

Plans include initiation of a formal project on Christmas trees and other timber-related crops at Berea, Kentucky, and intensification of the part-time effort on these problems in various silvicultural projects in the eastern United States and the Northwest. The naval stores research will include fundamental studies of the physiology of oleoresin flow and applied research on the improvement of gum extraction techniques. The extraction phase of the research will be coordinated with equipment development research in the forest engineering project of the Forest Service at Auburn, Alabama. The research on maple sap production involves studies of physiology of sap flow, maple orchard management, and the development of strains with higher sugar content and sap yield, all in cooperation with the University of Vermont.

Research on Christmas tree production includes the development of types of trees better adapted to Christmas tree use, as well as intensive cultural methods for diverse species, sites, and markets. Research on the miscellaneous timber-related crops such as greens and medicinal plants will center on ways to increase the supplemental income to forest owners from this source.

Research on this project is closely coordinated with the naval stores and maple sugar processing of the Southern and Eastern Utilization Research and Development Divisions of the Agricultural Research Service. Some phases of the Christmas tree and maple sap production are studied by State agencies and universities often in cooperation with the Forest Service.

The annual Federal scientific effort devoted to the research by the Forest Service is 11 professional man-years.

Program of State Agricultural Experiment Stations

Research on Christmas trees is active in experiment stations of several states. Studies deal with selection and culture of major native or introduced conifers.

Studies on maple sirup yield and processing are in progress in several states.

Total, 7.4 professional man-years.

Progress -- USDA and Cooperative Programs

1. Naval Stores

Tree improvement research at the Naval Stores and Timber Production Laboratory, Olustee, Florida is aimed primarily at improving oleoresin yield. An arboretum was established in 1954 to obtain additional sources of variation in oleoresin yield and chemical composition which exist in various pine species found throughout the world. The performance of 159 acquisitions under north Florida conditions was reported in 1963. The European pines and the pines of the Southwestern United States appear to be least well-adapted to the Southeastern environment. The Asiatic species of pine, although of slow growth and of comparatively poor form, seem to have a higher potential for survival. The poor showing of the Mexican pine species is similar to the performance reported earlier in east Texas.

Most gum producers integrate naval stores production with other forest products, thus requiring modification of standard procedures to operate most effectively. Such a modification has been developed for permitting 4 years of gum production and still meeting the requirements for pole production on the worked-out tree. A staggered production of 2 years on the front face and 2 additional years on the back face utilizing 65 percent sulfuric acid and intensive streaks 1-1/4 inches high produced 12 percent more gum in slash pine and 22 percent more in longleaf pine than did standard treatment on a single face for 4 years. In addition, pole-grade trees were left.

Producers have long needed an effective method of predicting the age at which slash pine plantations will have sufficient faces to be worked economically. By applying appropriate survival values to a growth predicting equation developed at the Naval Stores and Timber Production Laboratory, the number of trees per acre above the minimum tapping size (9 inches in diameter) can be forecast for plantations of any given site quality and stand density.

Results show that spacings below 10 by 10 feet have a small percentage of stems that can be worked, i. e., 9 inches and above, even on the best sites. At 16 years of age on an average old-field site, (site index 65 feet at 25 years) only 3 percent of the trees in an 8 x 8 spacing are 9 inches or above. In contrast, 47 percent of the trees in a 15 x 15 spacing are of naval stores size. At age 20, the percentages for the two spacings are 15 and 80, respectively. Only the wider spacings permit short rotations without intermediate thinnings, with 4 or 5 years of gum production preceding the harvest cut.

Inbreeding often results in depression of vigor and other economically important traits such as gum production. Although it will be several years before second-generation progenies at Olustee, Florida, can be evaluated for gum-yielding ability, the effects of inbreeding on several characteristics of parent trees and seedlings are helpful in evaluating seed orchards used for mass producing seed of high gum-yielding ability. Sound seed yield per cone, germinability, rate of seed germination, and seedling heights were all reduced in proportion to the degree of inbreeding from artificial crosses. These results indicate that inbreeding should be avoided by adequate seed orchard planning and management.

To determine the degree of natural inbreeding, it is necessary to find a gene marker. Such a marker was found in slash pine in a recessive gene which exhibited albinism, a form of chlorophyll deficiency. The natural selfing estimates obtained for 11 trees varied from 0 to 27 percent. Nine of the trees showed 5 percent or less selfing while two of them showed 23 to 27 percent, respectively. This information, coupled with the data obtained on depression of several traits from inbreeding, is being used to judge the extent of probable selfing in high gum-yielding slash pine seed orchards and in estimating the value of genetically improved seed.

2. Maple Sap Production

The cost of producing each gallon of maple syrup is closely tied to the sugar content of the sap, and it has been shown that sweetness in sugar maple sap is inherited. By 1962, criteria had been developed to grade sugar maple trees for sugar content and other desirable characteristics. Individual analyses of sap from more than 2,000 trees that year led to selection of 35 trees that were at least 50 percent above the average in sweetness. Analyses in 1963 further narrowed the number of desirable superior sugar maples. Using improved methods in initial selections during 1963, 3,300 trees were screened and 84 were found with substantially higher sugar yields than nearby trees. Some trees with 8 percent sugar content in the sap have

been located in comparison with an average of 2-1/2 percent. In addition, state groups have been organized in Maine, Massachusetts, New Hampshire, Vermont and New York to screen sugar maple trees for sweetness and other desirable traits. The superior individuals are being used as the basis for a breeding program to develop superior stock.

One means of propagating desirable clones of sugar maple for sugar bushes is by grafting superior clones onto seedling rootstocks, since mass production techniques for propagation by cuttings has not been perfected. A grafting study indicated that clonal stock budded on wilding seedlings varied fully as much in sugar content as did wilding seedlings. Grafting, therefore, may not be well suited for vegetative propagation of sugar maples selected for high sugar yield.

PUBLICATIONS -- USDA AND COOPERATIVE PROGRAMS

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II. WATERSHED, RECREATION, AND RANGE RESEARCH

A. FOREST SOIL AND WATER RESEARCH

Problem

All of the major rivers of the United States have headwaters in forests, associated rangelands, or alpine regions. To derive the greatest benefits and protection from these headwater areas, improved knowledge of the management of watersheds and streams is needed. More than half the waterflow of the country originates in such areas. Whether this waterflow is beneficial or harmful, is well-regulated, sustained flow of good quality or erratic and silt-laden is contingent to a major degree upon how the headwater lands are managed. Generally accepted estimates of water use indicate a doubling in demand by 1980. The most logical place to look for additional supplies of high-quality water, or to improve timing of streamflow, is in the headwaters. At the same time, there are constantly increasing pressures to use watershed lands for a variety of other products and services. Additional research is needed to determine how best to adjust these several uses to give the necessary protection and development to soil and water resources.

USDA and Cooperative Programs

This work includes basic and applied research into the relationships of soil, climate, vegetation, and water and the development of methods and techniques to: (1) increase water yields or improve the timing of such yields under a variety of climatic, soil, geologic, vegetative, and topographic conditions; (2) give adequate protection to soil and water resources while forest and related rangelands are being used for timber production, grazing of domestic livestock and big game, wildlife habitat, mining, and forest recreation; (3) rehabilitate forest and related rangeland watersheds that constitute sources of damaging flood runoff and sediment; and (4) aid forest soil development and improvement.

Ninety-seven (97) professional man-years of effort were expended by the Forest Service on this research during the past year.

Program of the State Agricultural Experiment Stations

The State agricultural experiment stations have basic and applied research in progress on a wide variety of soil and water problems relating to forestry. Work is in progress on fertilization practices and the response of individual species to nitrogen, phosphorus and potassium levels in the soil. Studies are underway on the relationship of soil moisture properties to survival and growth; of tillage and soil management factors to seedling performance; and influence of soil series and type on natural regeneration of forest cover. Other research seeks to determine the combined effects of different soils and different types of forest management on interception of precipitation, runoff, infiltration, percolation, evapotranspiration, soil water storage, and subsurface drainage. Interrelationships of drainage and site preparation in relation to reforestation are also being investigated.

The total research effort at State stations on forest soil and water problems amounts to 14.1 professional man-years.

One research project in Israel, involving two scientists, was conducted under Public Law 480. This project is producing a taxonomic revision of the genus Tamarix, a group of plants important in the United States because of their high consumption of water (phreatophytes).

Progress--USDA and Cooperative Programs

1. Water Yield Improvement

Research in the improvement of water yield is conducted in the different terrain, climatic and forest vegetational complexes throughout the Nation. The purpose is to explore the opportunities for improving the amount and/or timing of water yield through manipulation and management of the Nation's forested and related range and alpine watersheds. Water yield improvement research is being done in (a) alpine snowpack zones of the West, (b) forested snowpack zones of the East and West, and (c) in nonsnow forest areas. Research results are discussed under these breakdowns.

a. Alpine snowpack zone. The alpine zone includes the area above timberline. The climate is cold and winds move the snow about continuously. Snow cover is seldom over two feet deep except for protected pockets in ravines or behind obstructions where the snow may drift to depths of 30 feet or more. The drifts melt slowly in the summer, maintaining streamflow long after lower elevation snow has melted. There appear to be chances of increasing late season runoff even more by inducing more deep drifting of snow. Since evaporation losses from these snowpacks are negligible compared to evaporation losses from lower elevation reservoirs, storage of water in snowdrifts until mid- and late summer may increase storage efficiency.

Benefits of building snowfences along main ridge lines in the Colorado Rockies to increase snowpack in natural accumulation areas are further confirmed by this year's data. Despite very low snowfall during the winter, an extra acre-foot of water per each 70 linear feet of 8-foot high snowfence was available for streamflow on July 1, 1963. Drift-gage measurements in Wyoming have shown that about 70 percent more snow drifts along minor, downwind-oriented ravines than along relatively flat uplands. Studies are being made of methods of applying snowfences in ravines to augment natural snow accumulations.

b. Forested snowpack zone. Below the alpine area lie the forested and brush watersheds which accumulate snow and supply much of the streamflow of the western mountains and in the north and northeastern sections of the country. In the West, excellent opportunities prevail for improving water yields from this zone through management of the forest vegetation. Annual precipitation averages 30-50 inches of water, 45 percent of which appears as runoff. Preliminary studies of cutting patterns and other forest management practices which reduce interception and evaporation losses and increase the snowpack indicate possible increases in water yield as much as 4 inches (20 percent). Little is known about the effect of various forest densities, cutting patterns, slope direction, climatic characteristics, etc. upon snow accumulation, ripening, and melt.

The amount of water stored as snow, the areal extent of snow cover, and the pattern of snow disappearance significantly influence the volume and timing of water yielded from snowmelt. Areal snow cover disappearance on the Fool Creek watershed in Colorado is very closely related to discharge. When flows are corrected for retention storage of moisture in the soil and rock mantle, about 85 percent of the total April 15-July 31 generated runoff has taken place when 50 percent of the watershed is still covered by snow. Without correction for storage there is a difference in runoff timing between years of heavy and light snowpacks. In 1952, 60 percent of 890 acre-feet of runoff had passed the gage when half the area was snow covered. In 1950, only 30 percent of 570 acre-feet of runoff had left the area with the same areal snow cover.

Snow cover of the 1700-square-mile Kings River Basin in the southern Sierra Nevada of California decreases each spring at the rate of about 18 square miles per day; the equivalent snow line rises about 70 feet per day, regardless of the actual amount of snow. Water content of the snow cover increases 4 to 5 inches for each 1,000 feet rise in elevation up to 9,000 feet.

The patterns of snow deposition and melt were also related to runoff from two watershed conditions on the Allegheny Plateau in central New York. Relative amounts and timing of water available for runoff, and measured runoff, were compared between Albright Creek, 80 percent open land, and Shackham Brook, 84 percent forested--largely with 25-30-year-old coniferous plantations. Winter melt had disposed of half the total snowfall on Albright Creek by late March. Less than one-third of the snow had melted on Shackham Brook by the same date. Thereafter, the rate at which potential runoff from snow was generated increased much more rapidly on Shackham Brook. Thus, reforestation with conifers appears to concentrate spring snowmelt runoff by retarding the beginning of rapid melt and holding significant amounts of snow to be melted at higher spring temperatures.

A special strip cutting designed to maximize snow accumulation and delay melt has been applied to a large timber tract in the central Sierras of California. The treatment consists of logged strips oriented east and west to limit direct solar radiation and reradiation onto the snowpack. First-year results show that the "wall and step" forest, with slash windrowed, increased snow accumulation 25 percent over that of an uncut forest.

On the west side of the Oregon Cascades, first measurements of snow accumulation in 200-foot-wide clear-cut strips at 4,800 feet elevation showed 23 to 56 percent more snow than uncut strips. Similarly, water content of the snowpack was 35 to 66 percent greater on the clear-cut strips.

In the Wasatch Mountains of Utah, snowpack evaporation for a 36-hour period in a clearing between aspen stands at the 8,300-foot elevation was 0.087 inch of water. Windspeed averaged 7.5 miles per hour during the period. In the aspen stand, water loss for the same period was 0.082 inch, and winds averaged 5.7 miles per hour. Maximum observed daily water loss from snowpack in the aspen type was 0.101 inch with winds averaging 10.4 miles per hour. These data indicate that over-winter snowpack water loss from the east border of the Great Basin may exceed previous estimates of 3 inches, particularly when continuous snow cover persists for 6 months.

In the same study in Utah, total moisture use from a deep soil profile over the summer growing season amounted to 15.4 inches of water from bare soil plots, 19.3 inches from plots with herbaceous cover, and 25.2 inches from plots with aspen and herbaceous cover. These data point out that removal of aspen resulted in a soil moisture saving of approximately 6 inches, while removal of all cover (aspen and herbaceous understory) reduced moisture use by 10 inches.

The results of reducing transpirational draft on soil moisture were also demonstrated in forest stands of northern Idaho. At the time of maximum soil moisture depletion, during the second growing season after clear-cutting mature spruce-fir, the soil mantle in clear-cut blocks contained 11.4 inches more water than did the soil beneath undisturbed forest.

A study of soil moisture depletion in north central Washington illustrates how soil depths govern potential water yield increases due to timber harvest. Summer moisture use by lodgepole pine stands growing on pumice soils amounted to 2.90 inches on soil 2 to 3 feet deep, and 6.61 inches on soil 6 feet deep. The deeper soil still contained 8 inches of water, but the shallow soil approached the wilting point. Thus, it can be presumed that harvesting lodgepole pine on deeper soils will result in greater moisture storage and make more water available for streamflow.

On high-elevation ranges in northwestern Wyoming, significantly more snow accumulated in sagebrush-covered areas than in comparable grass-covered areas. This difference is likely due to the physical barrier of sagebrush crowns slowing surface wind and in inducing drifting of snow. During the melt period, a continuous sheet of ice 1 to 2 inches thick formed at the soil surface on the grass plots, but not on the sagebrush plots. Presence of such ice layers inhibits soil moisture recharge and increases spring peak flows.

Summer use of soil moisture by areas of undisturbed sagebrush cover and by areas where sagebrush cover has been eradicated by spraying are also being compared in the Wyoming study. In 1963, the second year following spraying of the treated plots, moisture levels in soils 8 feet deep were not significantly different at any time during the period May through December.

On study areas in northern Michigan, 40 to 80 percent of total annual ground-water recharge during water years 1961-62 and 1962-63 occurred during the snowmelt period. Early spring recharge was found to be related to differences in maximum snowpacks occurring beneath forest covers of different crown densities. Pine plantations, with dormant season crown densities of 80 to 85 percent, accumulated 1.0 to 1.5 inches less snow water than deciduous hardwood stands on corresponding dates. Pine plantations beneath scattered oak overstory, with crown densities of 60 to 70 percent, accumulated snowpacks intermediate to those measured in pure pine plantations or in pure hardwood stands.

Results from the first year of study on the influence of frost on water yields indicates that both concrete and granular types of freezing occur in the White Mountains of Arizona (elevation 9,300 feet). Concrete frost occurred to a depth of 6 inches or more throughout the winter in open grassland under at least 24 inches of snow. Only granular frost was present under mixed conifer and aspen types. Surface runoff was excessive where concrete frost occurred, and soil moisture recharge was greater on plots where only granular frost was present.

During winter in northern Minnesota it was found that sandy textured soils had less concrete frost than finer textured soils. Thinning conifer and hardwood stands reduced depth and duration of soil freezing because of increased snow accumulation. Soil frost was less severe under hardwoods than under conifers, but least severe under a mixed stand.

An 18-inch snow cover prohibits soil freezing with air temperatures as low as 4°F. in pole-sized northern hardwood stands in the Northeast. Twelve inches of snow limits soil freezing at 5°F., but 6 inches of snow furnishes protection only down to 25°F.

c. Nonsnow forest zone. The concept of water yield increase or change in timing of streamflow is based largely upon the fact that plants use water--some more than others. By varying the density or spacing of certain species, the amount of water used by vegetation may be increased or decreased, thus influencing the volume of water delivered to streams.

In the southern Appalachians, rainfall interception by hardwood forest litter was measured during 1961-62. About 1 inch of water reaching the forest floor was required to wet the litter to its maximum field water content of 215 percent moisture, by weight. Most of the evaporation loss from litter occurred during the time when the forest was dormant. Total interception loss during 1962 was 2.2 inches.

In the western Cascades of Oregon, dense Douglas-fir stands exert their major influence on water yield from late August to mid-November. Soil moisture measurements under an old-growth stand before and after logging show that soils remain at or near field capacity throughout the summer after logging. Water loss from a 4-foot soil profile was decreased 80 percent by logging. Removal of timber from only a portion of a 250-acre watershed has increased minimum streamflow 12 to 22 percent.

At Coweeta Hydrologic Laboratory in western North Carolina, significant increases in water yield have appeared in all of four 3-month periods during the past year from a 22-acre watershed converted from hardwood to grass in 1959-60. In the previous three years no significant change in total water yield had occurred, contrary to the belief that grass uses less water than forest. The increase is roughly parallel to decreasing net production of dry matter of the grass stand.

In another study at Coweeta, soil moisture content of a 50-foot-square forested plot, with soil surface covered with plastic film, has been studied for 3 years. Net growing season water losses from 17 feet of soil have been: 18 inches (1961), 11 inches (1962), and 8 inches (1963). During dormant seasons, parts of these amounts of summer losses were replaced by moisture moving from adjacent soil. At the end of two complete years after covering, moisture loss from each foot of soil down to 17 feet was, uniformly, 0.8 inch of water.

In the fifth growing season following the 1957-58 treatment of 4 gaged watersheds on the Fernow Experimental Forest, the increase in flow from the commercially clear-cut watershed was relatively small but still significant; it amounted to 1.4 area-inches. Changes in flows from the watersheds receiving lighter cuts were no longer significant.

The riparian zone of the Dilldown watershed in northeastern Pennsylvania is occupied by a residual high forest of mixed hardwoods and conifers. Daily evapotranspiration from this zone is reflected in fluctuations or oscillations of the daily hydrograph. Daily low streamflows coincide with the warmest time of the day when transpiration opportunity is greatest, and daily high flows occur as a result of minimum transpiration rates during hours of darkness. In a study this past year, daily losses were related to streamflow volume and a climatic variable, vapor pressure deficit. An equation was developed whereby daily losses from the riparian zone can now be predicted. Such predictions will be useful in determining the effectiveness of riparian treatments.

Phenoxy herbicides, often used to control riparian vegetation for increased water yield, can be used with no risk to water consumers if properly applied. Two formulations of 2,4,5-T were sprayed on streambank vegetation with a portable mist blower along streams in central Pennsylvania and northern New Jersey. Periodic water samples were taken at upstream and downstream locations for taste and odor testing by a panel of experts. Light contamination was found only within the treated reach immediately after spraying and after the first large storm. No contamination was found downstream. Also, it was found that contamination decreases in raw streamwater with passage of time, and rapidly after chlorination.

An increase in usable water has resulted from removing and spraying the canyon bottom vegetation of Monroe Canyon, at San Dimas Experimental Forest in southern California. Stream pollution has not resulted even though the riparian zone and immediate side slopes were sprayed repeatedly with herbicides. Also, soil samples show no traces of herbicide the first month after spraying.

Controlled clipping of Tamarix pentandra, a widely distributed southwestern phreatophyte, indicates that increased frequency of clipping increases mortality and decreases foliage production as well as carbohydrate root reserves. Two-week clipping frequency was most effective in killing tamarisk. The effect of submergence is also being studied, showing so far that plants 8 to 16 feet high have survived root and partial crown inundation for 12 months.

Water loss from soil and plants requires vast amounts of energy--solar radiation. In an effort to better understand evaporation and transpiration processes, an electronic device for totalizing solar and thermal radiation has been developed in Colorado. It is designed to facilitate sampling the great variation from place to place, inherent in topographically rough landscapes and forests. With battery power it is portable and is accurate, and relatively inexpensive. Applied to measurement of hermispherical and net radiation under lodgepole pine stands of different densities, the device showed that the magnitude of each category of radiation was closely correlated with canopy coverage and with the summation of basal diameters.

2. Prevention of Watershed Damage

a. Timber management. There are many thousands of acres of forest and related lands that are in good watershed condition. Increasing demand for use of these lands for timber harvesting, grazing, recreation, and wildlife requires that special attention be given to maintaining stable soils and controlled streamflow. Research in this area involves development of land-use practices that give special attention to the prevention of watershed damage.

Landslides and debris flows are common phenomena in southeast Alaska. Aerial photos show that 13 slides, involving about 32 acres in total, took place in Maybeso Creek valley during the 100 years before logging. Recurrent photo coverage shows that 116 slides and debris flows, affecting about 119 acres, have occurred in the valley since logging began. Most of these occurred in October 1961, generally 4 to 5 years after logging. Rainfall is one of the most apparent triggering forces, so it appears that logging and rainfall have combined to accelerate landslide occurrence Heavy rains have occurred with much greater frequency than have slides in unlogged areas.

The reconnaissance study also showed that slopes of 70 percent or more are highly susceptible to landsliding when conventional downhill high-lead logging is used. As flow-prone soils of southeast Alaska have little cohesive structure, loss of root systems as a stabilizing influence in the soil mantle may be an important factor after logging. Increased slide frequency may reflect destruction of interlaced root systems by high-lead skidroads as well as death and gradual deterioration of root systems after logging.

A new technique for tracing soil particle erosion was tested at Wenatchee, Washington. Radioactive ferric^{59} chloride in solution was placed directly on the soil surface in the field. All of the material was retained in the surface 1 inch of soil, 92 percent in the surface 0.3 inch. Only 0.6 of one percent of this was water soluble. From line and spot applications of the isotope even slight downslope movements of soil particles were detectable.

Soil conditions were compared on areas recently logged by tractor and high-lead logging methods in the Oregon Cascades. The surfaces of several clear-cut units were divided into four disturbance classes: undisturbed, slightly disturbed, heavily disturbed, and compacted. Both logging methods resulted in similar proportions of slightly and deeply disturbed surface. However, the tractor-logged units contained 18 percent more compacted area than did areas logged by the high-lead method. Furthermore, the high-lead units contained greater amounts of undisturbed area. Surface-soil bulk density values for the deeply disturbed and compacted classes were significantly higher than prelogging values, indicating a decrease in soil porosity. Compaction normally results in increased runoff and erosion. However, these effects can be minimized if slopes are gentle and roads properly located.

In central Idaho, two study compartments were established on steep, granitic slopes to compare erosion resulting from logging by jammer and high-lead methods. Two roads were built into the jammer area in 1961, but the high-lead area contained no roads. Both compartments were logged in 1962. Erosion from both areas was

negligible before they were disturbed, but after road construction, erosion from the jammer compartment amounted to 7,172 tons per square mile during spring runoff. Since logging, erosion from both areas has been:

Period	Jammer Area Tons/sq.mi.	High-Lead Area Tons/sq.mi.
Summer-fall	552	0
Fall-spring	371	3
Spring-summer	213	25

The principal contributing factor to accelerated erosion in this area apparently is the presence of new roads. The decrease from 7,172 tons/sq.mi. indicates that erosion from roads diminishes rapidly but remains high for some time in comparison to erosion from tree-removing activities.

Land use is closely allied to soil and geological conditions in northern lower Michigan. When such land-use categories as cultivated land, pasture, wild nonforest, and forest land were used as independent variables, it was found that the sediment yield of 20 sample watersheds could be predicted. Cultivated land had the highest sediment yield averaging 2300 lbs/day/sq.mi. Pasture land yielded second, averaging 1,800 lbs/day/sq.mi. Wild nonforest and forest lands yielded only 74 and 330 lbs/day/sq.mi., respectively. Approximately two-thirds of average sediment loads from all land classes are attributable to erosion of land surface, while the remaining one-third originates from eroding streambanks.

The role of wildland soils in preventing floods and modifying runoff is closely related to their water storage capacities. Storage capacities of 25 soil types in Hawaii were found to be correlated with land use and vegetative cover. The top foot of forest soils has larger pores and higher water-holding capacities than do soils under cultivation, in pasture land, or in idle grassland. High water storage capacity and large pores facilitate infiltration and percolation, making soils under forest in Hawaii the most effective in controlling storm runoff.

b. Logging road location and construction. A large proportion of sediments reaching stream channels from forested lands originates from roads. In the construction and maintenance of roads, soil disturbance is inevitable. Yet, roads are a necessary part of the process of converting overmature timber to managed stands. And, as logging pushes further into the steeper, more inaccessible forests, soil disturbances from road construction will increase. Procedures are being developed for minimizing erosion from road surfaces, restoring stability to fill slopes, and regaining overall absorptive capacity of disturbed soils as quickly as possible.

In the mountainous country of western Oregon, construction of logging roads disturbs 6 to 8 percent of a watershed area. Immediately after construction of 1.65 miles of new road in a 250-acre watershed in western Oregon, sediment concentration in runoff increased to 250 times that of an undisturbed watershed. Two months later, sediment levels had diminished to only slightly above preconstruction levels.

Stability of fill slopes of newly constructed roads may be enhanced by establishing a good grass cover. In many instances, however, grass cover is difficult to establish because broadcast seed rolls off the crusted soil of the fill. Loss of seed is particularly severe when firm rounded seeds, such as yellow sweetclover or cereal rye, are used. Laboratory tests in Idaho have shown that seed retention may be markedly increased by seeding upon a hay mulch, wet or dry paper netting, a wet soil surface, or on a "pockmarked" soil surface.

Logging roads may have other important hydrologic effects on the forest. In mature spruce-~~fir~~ in northern Idaho, seepage flow along four 100-foot road sections was measured for 37 consecutive midsummer days. Total flow from 1,250 square feet of road cut during this period was 17,174 cubic feet--nearly one-fourth acre-foot. On insloped roads this drainage would be diverted along the inside ditch to a culvert or stream channel, and thus lost from the soil mantle below the road. On outsloped roads nearly all this drainage would be returned to the soil below the road.

c. Range management. Forest-associated rangelands are a primary source of waterflow. They also provide needed forage for big-game herds and large numbers of domestic livestock. Continued grazing use of these lands is dependent upon recognizing or establishing plant cover requirements for maintaining stability on these sites.

Approximate site conditions required for effective watershed protection on range sites in central Utah have been derived from a study on the Wasatch Plateau. Analysis of precipitation records shows that these ranges would rarely be subjected to rainfall in excess of 2.58 inches per hour. Therefore, sites capable of retaining this amount of precipitation would seldom produce overland flow. Infiltrometer plot studies indicate that this amount of retention will be attained or exceeded on sites where one of the following conditions exist:

(1) Bulk density of the surface 4 inches of soil less than 0.97.
(2) Total protective cover (plants, litter and stone) at least 85 percent.
(3) Noncapillary porosity of the surface 4 inches of soil at least 22 percent.

Any one of these three conditions can be considered as a protection requirement. However, the requirement can be less stringent if all three site factors are considered. Where soil bulk density is too high for effective runoff control, erosion can still be minimized by a dense, protective plant cover.

Precipitation, runoff, sediment, and ground cover measurements have been made since 1952 on three watersheds in the semidesert type of New Mexico. During 1952 to 1958 the watersheds were grazed partly as open range and partly under fence, year-long or overwinter. Grazing control was established in 1958 to allow only overwinter use to a utilization goal of 55 percent removal of the annual growth of alkali sacaton (Sporobolus airoides), the principal forage. Average precipitation and runoff amounts are unchanged. However, ground cover has doubled since 1958, and sediment production has been reduced to less than one-fourth the previous amounts.

3. Rehabilitation of Damaged Watersheds

This research is designed to develop techniques and management practices which will restore satisfactory surface flow and streamflow conditions and stabilize and improve soils on forest and range watersheds that have been damaged through past use and remain in unsatisfactory condition.

a. Abandoned farmlands.

In years past, many thousands of acres in the piedmont and upper coastal plain of the Southeast and South and other areas in the Lake States and the Central States were cleared from forest and put under clean cultivation. Serious erosion and lowered productivity of the land have resulted in abandonment of many areas. Difficult problems now prevail to stop the active erosion and to reestablish trees and other protective vegetation on those lands.

Some piedmont gullies are difficult to stabilize by planting alone. "Vertical mulching" is being tested at the Union Experimental Forest in South Carolina as an aid in rehabilitating eroded areas that feed larger gullies. The gullies are smoothed with a bulldozer, seeded, and fertilized as usual. Trenches 6 inches wide and 42 inches deep are then dug on the contours and backfilled with sawdust. These trenches are spaced to store 2 inches of rainfall, thus prolonging and increasing infiltration. The treatment appears successful at the end of one full growing season.

Annual runoff and sediment production of small watersheds in the hilly uplands of north Mississippi vary in relation to land use and cover types. Runoff from watersheds with similar soils decreases in the order: Corn and pasture > abandoned fields and depleted hardwood forest > pine plantations. Annual sediment yields decrease in the order: Corn > pasture > abandoned fields and depleted hardwood forest > pine plantations and mature pine-hardwood forest. Extremes in annual sediment production range from 43 tons per acre from a cultivated watershed to a few pounds per acre from pine plantations. Sediment from abandoned fields with dense native grass cover, and from mature pine-hardwood forest, seldom exceeds 0.5 ton per acre annually. These relations point out opportunities for reducing runoff and erosion by changing land use and plant cover. Pine plantations, established on actively eroding abandoned fields have, in 20 years, reduced sedimentation to an amount near the geologic norm for undisturbed climax forests.

Loblolly pine seedlings from seed grown in Caldwell County, Texas, outgrew those from three other sources by 3.7 feet in 5 years on droughty sands in north Mississippi. Anatomical differences observed in these seedlings tend to reduce moisture loss from needles, thus improving their chances for survival and growth in rehabilitating difficult sites. Their needles have less surface in proportion to volume than those from other sources. Rows of stomata did not vary among seed sources, but seedlings from the Caldwell County source had fewer stomata per unit of surface area and needle volume. Also, their needles have thicker epidermal cells and more numerous hypodermal cells in groups between the stomata, with the effect of thickening the peripheral tissue.

b. Damaged rangelands. Overglazed rangelands in Western United States are often important sources of floods and erosion. Rangeland soils are often thin and sites are harsh. Past efforts to reestablish protective vegetation have frequently failed. Research in development of new and better procedures for rehabilitation is underway in several areas.

Past research has shown that the plant cover and soil characteristics of rangelands strongly influence surface runoff and erosion. On the Wasatch Plateau in central Utah, recent studies have been concerned with more precisely defining these relations and learning the effects of plant cover restoration on depleted ranges by disking and reseeding to grasses. Results show that the infiltration capacity, determined by the inches of water retained on infiltrometer plots during 50 minutes of simulated rainfall, is influenced mainly by bulk density and noncapillary porosity of the surface 4 inches of soil. The density of protective cover afforded by plants, litter, and stones is of secondary importance. Soil stability, indicated by amounts of soil eroded from the plots, is largely influenced by protective cover and, to a lesser extent, by soil bulk density. Disking and reseeding to grasses increased infiltration and decreased soil erosion on sites where plant cover was initially greatly depleted and soils highly compacted. Conversely, on sites where plant cover and soils were initially in good condition, these treatments decreased infiltration. Moderate, late-summer grazing decreased the amounts of water retained on the infiltrometer plots from 2.29 inches to 1.71 inches during 50 minutes of simulated rainfall. During the same period, the amounts of soil eroded increased from 313 pounds per acre to 913 pounds per acre as a result of grazing.

Commerical fertilizers offer a means of hastening recovery of damaged game ranges in eastern Oregon and Washington, if vestiges of native vegetation remain. Applications of phosphorous, potassium, and nitrogen at various levels in combinations were studied in 1963. First-year response amounted to at least doubled production of air-dry plant material for most treatments.

A prefabricated concrete check dam for gully control was designed and installed in Colorado. The dam can be designed to fit a wide range of gully sizes, can be installed without specialized equipment, and should have a long service life with little maintenance.

c. Strip mined lands. Strip mining for coal is being extended to many hundreds of acres of forested watershed lands each year in the southern Appalachians. Freshly exposed strip mines can logically be expected to increase sedimentation and lower water quality in the affected areas. It is essential to develop methods for minimizing damage during mining and for quickly restoring a pleasing and productive landscape after mining.

A set or charts, based on highwall height and original slope angle, has been developed for predicting the area of strip mine disturbance. The average disturbed horizontal width of strip mines observed in this study was 231 feet. Each mile of contour strip mining results in 2 acres of highwall, 16 acres of coal pit, and 10 acres of outslope, for a total of 28 acres disturbed. For protection to watershed or downslope values, allowable depth of cut or height of highwall for contour strip mining can be specified in the planning stage.

Spoil banks formed as a result of coal harvest on six principal eastern Kentucky seams have a soil texture that should support good plant growth. However, pH values range from 3.3.to 5.0, and the presence of large amounts of soluble salts may interfere with seed germination, plant growth, or uptake of water by plants. A high specific conductance in acid spoils indicates elements toxic to plants. Sixty percent of the samples analyzed indicated only minor difficulties in revegetation, and 20 percent of the samples indicated major problems requiring the use of highly tolerant plants for revegetation. High concentrations of iron, manganese, sulphur, aluminum, and copper were found. In some instances, concentrations of single elements were high enough to inhibit plant establishment.

The cation exchange capacity of these eastern Kentucky spoils is low because most of the material contains less than 3 percent organic matter and very little clay. While exchangeable potassium and magnesium are extremely variable, most spoils contain only about one-tenth of the amount of exchangeable calcium considered adequate to support normal plant growth.

d. Burned watersheds. Fire-induced floods and erosion from steep, unstable watersheds are a serious problem in some parts of the country--particularly in southern California. Records show that flood peaks can increase 68 times and erosion rates can increase 28 times following fire. Floods and erosion at greatly accelerated rates not only impair watershed productivity but also are a threat to downstream population centers. Methods for quickly stabilizing destructively burned watersheds are being sought.

After the fire which destroyed the vegetation on the San Dimas Experimental Forest in southern California in 1960, the soils exhibited a lack of affinity for water which prevented rapid entry of moisture into the soil profile. A wetting agent was applied to the soil to permit more rapid infiltration and percolation by reducing the surface tension of rain water. This treatment reduced erosion 15-fold, decreased runoff 32 percent, and promoted four times more cover from seeded grass than the untreated areas. The wetting agent also reduced surface runoff and prevented grass seed from being washed downhill.

There are indications that the hydrophobic property of southern California soils is more than a problem of temporary soil dryness. It can exist in soils at fairly high moisture contents. The nature of the hydrophobic substance is unknown, but it is associated with either burned or unburned chaparral watersheds, and could be an important factor in the high rates of runoff and erosion in the San Gabriel Mountains. Approximately 60 percent of the soils on the San Dimas experimental watersheds are hydrophobic. Also, this phenomenon may influence water yield through a regulatory effect on moisture movement in the soil profile. The physical and chemical properties of these soils, and the influence of the nonwettable substance on moisture movements, will be further studied.

4. Soil Improvement

There are more than 25 million acres of wetland forests ranging from the bogs of the northern Lake States to the swamps of the southeast coastal plains. Most of these lands are headwaters for countless streams, and are recharge areas for groundwater supplies in certain localities, but support only low-growing heaths or degenerate forests. Although their inherent wetness makes management difficult,

wetlands have potential for greater forest site productivity through improved soil-water relations. Development of management alternatives which will upgrade productivity yet conserve regional water supplies is dependent upon the hydrology of these soils. There is a dearth of information on the water relations of wetland forests and soils.

There are striking differences between peat types found on the forested bogs of the Lake States. Although all contain great amounts of water at saturation, their characteristics of water release are quite different. Sphagnum moss peat in surface horizons contains 95 to nearly 100 percent water by volume at saturation. Total porosity consists primarily of large pores which release 0.80 cc. of water per cc. of peat between saturation and 0.1 atmosphere tension (Somewhat less than tension at field capacity). It displays good aquifer characteristics, having specific yield of 0.79 (5.91 gal./cu.ft.) and hydraulic conductivity of 118 ft./day. Decomposed and herbaceous peats from deeper horizons contain 80 to 90 percent water by volume at saturation. But, total porosity is mainly in small pores which are not easily drained at low tension. They retain 65 to 75 percent water by volume at 0.1 atmosphere tension. Specific yield is only 0.13 (1.0 gal./cu.ft.) and hydraulic conductivity is about 0.02 ft./day. Thus, a specific change in water table elevation in horizons containing loose, undecomposed moss peat will involve a great deal more water than will the same change in more dense horizons of decomposed peat. The hydrologic role of a bog will depend on the type of peat it contains.

Management practices resulting in extreme drying may have far-reaching effects on the hydrologic role of bog sites. Air-dry peat materials are often difficult to rewet, and considerable change in structure occurs in drying. A study this past year illustrated that artificial drying or disturbing peat samples significantly lowers their moisture-retention capabilities.

5. Public Law 480 Projects

a. Monographic revision of the genus Tamarix. The genus Tamarix, native to the Middle East, includes saltcedar, one of the most troublesome phreatophytes of Southwestern United States. Considerable study is being made of methods for controlling and replacing it with plant cover having a lower water requirement. To better understand the growth requirements of Tamarix as an aid to control, a research project in Israel under Public Law 480 is studying the taxonomic characteristics and occurrence of the several species. Material from herbaria throughout the world are being examined by the project staff, and representative specimens collected in the United States are included for identification. Observations of living plants have been made throughout Israel and Turkey. It is felt that the flowers are the most efficient means for natural subdivision of the germs, and marked progress has been made in gaining understanding of the diagnostic characters of these parts. A revised monograph of the genus will be published as soon as all the data are assembled.

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B. FOREST RECREATION RESEARCH

Problem

Visits to the National Forests have soared from 5 million visits in 1925 to an estimated 130 million in 1964--a 26-fold increase in 40 years. Recreation use of National and State Parks, public reservoirs, and other public and private outdoor facilities has increased in a similar manner. Not only the amount, but the characteristics of outdoor recreation are changing rapidly. Public and private land managers need reliable methods for estimating the amount and type of recreation they must provide today and during the coming years. Much of the burgeoning use is concentrated, and many recreation sites are worn and depleted. Administrators must know how to restore damaged sites, how to better plan and manage for recreation at new sites and in the surrounding forest areas, and how to coordinate recreation with other land resource uses.

To meet this obligation, we are learning more about the physical and biological requirements of recreation areas and the management of their soils and vegetation. We are learning more about the people who go to the forests, woodlands, and wilderness areas for their outdoor recreation enjoyment. And, we are learning more about the impacts of recreation upon the economy and upon other forest resources in the area.

USDA and Cooperative Programs

Research at 8 of the 10 Forest Experiment Stations is underway toward answering these problems. Studies fall into three broad categories--those dealing with forest recreation use, those directed at the forest recreation environment, and those dealing with the economic aspects of forest recreation. Each Station is concentrating its studies on selected critical problems, often interregional in scope, rather than attempting a program of research embracing the broad spectrum of problems found in its geographical region. Staffing varies according to the research emphasis, and currently scientists from 8 different disciplines make up the 20-man staff.

A total of 20 man-years of Forest Service scientific effort was devoted to forest recreation research during the past year.

Program of State Experiment Stations

Forest recreation research is represented in the Hatch program by only one project. Research here is addressed to establishment of the "carrying capacity" of different forest sites for different recreational uses. Primary factors being measured are recreational effects upon soil and vegetation.

The professional time devoted to forest recreation research at the State Stations is 0.3 man-years.

In the new McIntire-Stennis program, research in forest recreation is much more considerable, with 9 projects, addressed to a variety of problems.

Progress -- USDA and Cooperative Programs

1. Effects of recreation on forest environment

Vegetation is not only physically damaged in heavily used recreation sites, these areas frequently suffer from soil compaction which inhibits the growth of new vegetation. In the Sierra Nevada, we found that heavily used sites had less than 1/3 as many young trees per acre (seedlings to 5.0 inches d.b.h.), only 1/3 as many shrubs, and less than 1/2 as much leaf litter as surrounding unused or slightly used sites. Methods of assessing soil compaction showed that bulk density measurements did not provide consistent results. The Proctor penetrometer, however, proved to be durable, easy to use, and sensitive enough to show compaction differences between moderate and heavy recreation use. This instrument can indicate those areas where compaction is approaching a degree that will cause serious damage to vegetation.

Interviews with visitors at Minnesota's Boundary Waters Canoe Area showed that most visitors did not notice logging operations which were limited to protect scenic values. Among those who did notice the logging, only a few were bothered by it. It seems the conflicts between recreationists appear much more serious. Solitude and wilderness are subjective concepts and hard to define, but research has shed some light on how visitors see the wilderness in the Canoe country. Many different types of visitors come to the area--canoeists, boat campers, fringe campground campers, summer home users, resort guests, and one-day fishermen. Canoeists are the largest group and see the wilderness differently than the other visitors. They considered wilderness the main appeal of the area. Most canoeists set a high standard for their wilderness; the more visitors an area had, the fewer canoeists saw it as wilderness. But this loss of wilderness was fairly gradual unless motorboats used the area. Even light motorboat use destroyed the wilderness environment as most canoeists saw it. The area that met their image of wilderness was smaller than that envisaged by other visitors and smaller than the officially established area.

The other types of Boundary Waters visitors--most of whom used motorboats--had a different picture of the wilderness. Wilderness was a less important attraction for most of them--fishing and scenery equalled or exceeded wilderness as an appeal. Their "wilderness" was not lost even where recreational use was fairly heavy. Simple roads were accepted. A large area, much of it outside the boundaries of the Canoe Area, met these standards and was viewed as wilderness by the boaters. These images seem to explain some of the distribution patterns. They also suggest ways of zoning to increase the recreation capacity of the area.

2. Forest recreation use

Campers come in many varieties. Some prefer to be surrounded by many of the conveniences of home and the sociability and security of other people. In contrast, other campers pack their equipment across miles of rugged country in search of solitude and the experience of roughing it in truly wild surroundings. Camping tastes of all shades lie between these extremes, and the needs of different campers cannot be fulfilled by one type of campground. Seven suggested types of campgrounds are described in a Utah report.

Variation in design and layout within the campground itself may be desirable to protect areas from deterioration and to satisfy the needs of gregarious groups as well as those seeking privacy. In an Oregon study we found that 27 percent of the filled single-family campsite units were occupied by two or more families, even though there were empty and available single-family units in the same campground.

The need for campground variety was substantiated by a study of State Park campers in northeastern Pennsylvania. About 2/3 of the campers wanted to be within 50 to 100 feet of other campers. Most of the remaining third preferred to camp 250 to 400 feet from other campers; and a small proportion wanted campsites only 10 to 15 feet apart.

Further information on the importance of campground design and its effect upon the popularity of some campsites and nonuse of others as well as an indication of regional differences in taste were highlighted in a Rocky Mountain study. Campsites within 50 feet of the parking area were used more than those over 50 feet; sites more than 100 feet apart were used more often than those closer together; and sites more than 50 feet but less than 200 feet from a fishing point were preferred.

Day users (picnickers) numbered about the same as overnight campers, but day users accounted for less than 10 percent of the total visitor hours--their average stay was 2-1/2 hours. Campers averaged 27-1/2 hours.

Campgrounds along or near highways on California National Forests received a markedly different kind of use than campgrounds off the beaten track. Visitors were more often without children, traveled in smaller groups and typically stayed only overnight. Less accessible campgrounds were occupied mostly by 4-person families who stayed for either a weekend or an entire week.

Can attendance at a "bellwether" or indicator campground be reliably related to campground attendance throughout an entire administrative unit? This idea was studied in California on a 23-campground district of the heavily used Stanislaus National Forest. The results indicate great promise. On an average day, total attendance could be estimated within 10 percent of true attendance from counts made at only one campground. Between-year stability also proved to be good. During the two years of the study, patterns of attendance were quite stable, and estimates for an entire season's use could be made with even greater accuracy than for single days.

At winter sports areas, records of tow-lift tickets or restaurant receipts can be related to recreation use. Receipts related to use over a two-month period provided estimates within 18 to 24 percent of true attendance for an average day, and estimates within 8 percent of true attendance for the two-month period.

An analysis was made of the location of 4,100 deer kills during four hunting seasons on 14 wildlife management areas in North Carolina. Most deer were harvested close to roads and trails, but important differences were found between the piedmont and the western mountain region in the use of forest access. In the steep, rugged mountain areas, largely populated with rural residents, hunters made exceptionally good use of all portions of the forest, and their kills were

uniformly distributed. Hunters in the gently rolling piedmont, on the other hand, coming from nearby cities, apparently stayed close to access and did not penetrate into the more remote sections. In all areas, trails were used as heavily as roads, indicating that for hunting areas where additional access is desired, trails, which are less expensive and usually more aesthetic may be considered.

3. Economic aspects of forest recreation

Owners of small woodlands in Ohio who provide forest recreation for a fee were compared with neighboring woodland owners who are not in the recreation business. Recreation providers were more often (a) nonfarmer businessmen who had attended college, (b) newcomers to the area, (c) from an urban background, (d) in debt, (e) active in community affairs, (f) avid readers, and (g) were themselves vigorous participants in outdoor recreation.

In a related Ohio study of fee-charge woodland picnic areas, more than one-third of the entrepreneurs lost money in 1962. The more successful enterprises were within 30 to 40 minutes of a population center, were better financed, and offered a variety of activities such as outdoor game areas (softball, volleyball, horshoes, etc.), boating, fishing, and swimming. A major management problem for the owners is keeping their enterprises neat and clean. Many of the less successful entrepreneurs recognize that lack of facilities limits their opportunity, but state they have been unable to expand because of insufficient capital.

The socio-economic characteristics of family campers in the Huron-Manistee National Forest in lower Michigan were compared with the populations from which they came. Most of the campers were in the middle and upper-middle income brackets, and education levels are fairly high. A large proportion of the campers are from professional,managerial, and skilled labor occupational categories. The study suggests that visitor information programs should not underestimate campers' level of understanding, and that recreation-use fees would not be a serious barrier to this type of Michigan camper.

Similar results were obtained in Oregon, where it was found that most forest campers had significantly higher incomes than the population at large. The Oregon study also showed that the majority of the campers came from urban areas, but had rural or small-town family backgrounds.

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C. RANGE MANAGEMENT

Problem

Forage production on extensive areas of rangeland is far below the potential and fails to meet the demands for livestock and game grazing. Many areas, particularly in the western mountains, have been so damaged that watershed values are seriously impaired. Management of these lands is often complicated by variable and droughty climate, highly erodible soils, and vegetation that will not stand close grazing use. Furthermore, livestock grazing must be correlated with wildlife use and often with timber production. Improved management practices must be developed to allow continuous forage production in keeping with other uses and values.

Special phases of the problem are: (1) to determine characteristics and requirements of range vegetation, (2) to determine forage values, classify range condition and trend, and develop improved vegetation measurement techniques and range inventory procedures, (3) to develop optimum management systems to obtain maximum production and efficient use of forage on the various types of rangeland, (4) to determine effects of fire on vegetation and soils and to develop practical guides for its use in controlling undesirable plants, increasing forage production, and improving quality, and (5) to determine the identity and ecological relations of rodents and other range pests as a basis for their control.

USDA and Cooperative Programs

This is a continuing, long-term program of both basic and applied research at numerous locations in the various range plant communities of the West, Midwest, and South in cooperation with State colleges, universities, and agricultural experiment stations; with the Smithsonian Institution, Bureau of Land Management, Bureau of Indian Affairs, Fish and Wildlife Service, Agricultural Research Service, numerous herbaria, private companies, and livestock associations or individual ranchers. In addition there are two PL-480 projects: germination of seeds of desert plants (Israel) and studies of botany, ecology, and biology of the principal species in mountain pastures of semiarid regions (Spain).

The Forest Service scientific effort involved in this research totals approximately 45 professional man-years.

Program of the State Agricultural Experiment Stations

Several of the States, particularly in the West, are conducting basic and applied research relating to the use of forest lands for the production of livestock. This research is primarily in the following categories: (1) classification and mapping of range sites and condition classes with emphasis on better understanding of the forest-range environment; (2) manipulation of vegetation species composition by chemical or biological means; (3) revegetation of depleted areas to native or introduced plant species; and (4) grazing management research with cattle, sheep, and goats with special attention to season of use, systems of management, and intensity of stocking.

Since much of the forest land has multiple-use value (timber, livestock, wildlife, recreation and watershed) the pattern of management is complicated and the approach to research rather difficult. Progress can be made only with the combined efforts of scientists in many fields, including range ecologists, agronomists, plant physiologists, foresters, and animal scientists. The ultimate objective of the range research program is the realization of grazing potential from forest lands consistent with proper management of this resource for other purposes.

It is estimated that the total research effort of the States relating to range management on both commercial and non-commercial forests is approximately 5.2 professional man-years.

Progress--USDA and Cooperative Programs

1. Characteristics and Requirements of Range Plants

a. Ecology and physiology. Growth of grass seedlings in solutions containg extracts from various plants of northern Arizona was 30 to 100 percent less than growth in water only. The inhibitory effect was more pronounced, especially on blue grama (Bouteloua gracilis), in extracts from tree leaves than from grass leaves. In the extract from Utah juniper (Juniperus osteosperma), growth of bottlebrush squirreltail (Sitanion hystrix) was almost completely stopped and growth of blue grama seedlings was only 10 percent as much as in water only. Seedling development in extracts from pinyon (Pinus edulis) and ponderosa pine was nearly as poor. Though blue grama made relatively good growth in extracts from grass leaves, squirreltail was severely depressed, even when grown in an extract from its own leaves. The extract from the leaves of Arizona fescue (Festuca arizonica) was more detrimental to ponderosa pine seedlings than extracts from other grasses. These findings indicate that inhibitory effects as well as direct competition may necessitate control of some plants before desirable forage species can become established. Also, some causes of plant succession or changes in plant composition under different range management practices are indicated.

Temperature of thiourea solutions, which are used to break dormancy of bitterbrush (Purshia spp.) seed for spring planting on deer winter ranges, has been suggested as a possible cause of reduced germination and seedling deformity. Laboratory tests in California, using a 5-minute soaking of the seeds in 3 percent thiourea solution showed temperatures above 140° F. significantly reduced germination but did not cause deformity of seedlings; above 170° F. all seeds were killed. Below 60° F. the soaking treatment reduced the amount and speed of germination.

Germination of eight grasses and one forb, which are common in mountain grasslands of western Colorado, was little affected by various temperatures within a range of 59°-86° F. After 4 weeks, germination of 85 to 98 percent was recorded for nodding brome (Bromus anomalus), mountain brome (B. carinatus), Thurber fescue (Festuca thurberi), and aspen fleabane (Erigeron macranthus). Moistening and storing the seed at 40° F. for 6 weeks increased germination of Idaho fescue (Festuca idahoensis) from less than 5 percent before treatment to 42 percent. Germination of other grasses including subalpine needlegrass (Stipa columbiana), Letterman needlegrass (S. lettermanii), and prairie junegrass (Koeleria cristata) was poor. These tests are increasing our understanding of mountain grassland ecology and are complementary to grazing management studies underway.

Heavy needle litter suppresses emergence of herbaceous species. Under a ponderosa pine overstory in eastern Washington, up to 13 times more grass seedlings were counted where the litter had been removed than where it was undisturbed. Where litter, once removed, was subsequently permitted to accumulate and also where, after planting, litter was replaced, significantly more seedlings were present than where seed was broadcast on undisturbed litter.

Root systems of mountain muhly (Muhlenbergia montana), Arizona fescue, and blue grama on ponderosa pine-bunchgrass ranges in Colorado that had been grazed by cattle for 17 years were less extensive and weighed less than those within ungrazed areas. Less root growth with heavier grazing corresponds with previously observed lower vigor of the aerial portions of the forage plants on these ranges. In soil monoliths 3 inches by 2 feet by 6 feet deep, total root weight averaged 25.48 grams where the plants had not been grazed, 21.44 grams where they had been moderately grazed, and 15.11 grams where grazing had been heavy. Roots of the relatively unpalatable forbs, fringed sagebrush (Artemisia frigida) and Rocky Mountain pussytoes (Antennaria apica), were less affected by grazing treatments. RM

Foliage removal to ground level at a certain time had a pronounced effect on production of certain mountain grassland species the following year. Clipping of Idaho fescue during late June (flower stalks in boot) and in mid-September (seed disseminated) resulted in significantly greater herbage production the following year than on adjacent checkplots. Clipping mountain brome during late June (flower stalks in boot) and mid-July (flower stalks out of boot, before anthesis) also increased production the following year. Number of flower stalks of both species increased significantly following clipping in late June and mid-July. However, both number and height of Idaho fescue flower stalks, as well as percent of plants flowering, were reduced by clipping at the time seed was ripe in late August. RM

Bebb willow (Salix bebbiana) is the most abundant willow in the Black Hills, but it exhibits the poorest vigor and highest mortality. Because of its importance as deer browse and streambank cover, it has been the object of rather intensive study. Recently, it was determined that the willow borer (Sternochetus lapathi), while common and destructive in local areas, is not a major cause of widespread willow losses. On almost all sites examined, vitality of Bebb willow appeared to be related to available soil moisture. When water levels are low, however, other causative factors such as the willow borer or browsing become more critical, and the general weakening of the plants may eventually result in their death. RM

In the PL-480 project in Israel, studies of germination-regulating mechanisms were extended to several additional species. Hyoscyamus desertorum seeds were found to require a combination of light with high temperatures (25°-30° C.) for germination. Seeds of Artemisia monosperma likewise were absolute requirers for light, even at the optimal temperature of 15° C. Oryzopsis miliacea seeds were inhibited by continuous light and promoted by light breaks. In Panicum turgidum, a drought-resistant perennial grass inhabiting sandy soils, germination was somewhat inhibited by continuous light, but the requirement for dark could be satisfied by as little as 24 hours. Alternating temperatures were more favorable than constant ones.

2. Range Vegetation Evaluation

a. Forage value. With increased interest in deer habitat in the Pacific Northwest, research has been expanded to include investigations of the quality as well as quantity of the native bitterbrush. Laboratory analysis of bitterbrush showed ash content to be significantly higher and crude fiber lower in unthinned pine stands of central Oregon than in stands thinned to three different levels. However, thinning had little immediate effect on crude fat or crude protein content of bitterbrush.

Most soils in the southern pine-wiregrass region are deficient in phosphorus, and forage plants reflect the deficiency. With the application of 1 to 2 tons per acre of crushed rock phosphate, increases of 0.11 percent in phosphorus composition of pineland threeawn (Aristida stricta) and 0.36 percent of goobergrass (Amphicarpum muhlenbergianum) were obtained on Florida ranges. This low-cost material shows promise as a means of raising the phosphorus content of the native forage species to acceptable levels for adequate animal nutrition. This is especially important in young pine plantations where fire must be excluded.

b. Vegetation measurement and sampling. Over the years much has been learned about range plant communities and interrelations of their many components. Progress has been made in electronic processing of data and in the development of instruments and methodology for rapid and accurate measurement of both biotic and physical characteristics of range ecosystems; but better methods are needed, particularly for quantitative measurements of vegetation. A servicewide symposium was held in 1962 with emphasis given to range research methods; papers and committee reports were recently released in a formal publication. In addition to an introductory discussion of why range research is conducted and some of the associated difficulties, four major subject areas are considered: vegetation measurement and sampling, site evaluation, measurement of range utilization, and the design and conduct of grazing experiments.

Rating and ranking methods offer distinct possibilities for providing efficient estimates of various plant attributes in numerous vegetation types. Density, aerial cover, basal area, and weight are criteria for which these methods are appropriate. For production estimates, three plots in a set or cluster are ranked according to weight of herbage present, the highest ranking plot is clipped at the first location, the middle rank at the second location, and the lowest rank at the third location. The process is repeated until sufficient plots are clipped. A preliminary estimate of 150 percent efficiency compared with the usual random sampling has been obtained with this method.

A new method was developed for obtaining quantitative measures of browse production. The twig-count method converts a count of twigs on a plot to weight of browse by use of an average weight per twig for individual species. Twigs are clipped to a predetermined diameter which is based upon knowledge of the average portion of a twig that deer usually consume. For five hardwood species in Pennsylvania, 39 plots each containing 100 square feet were required to sample the production within 20 percent accuracy. Utilization was determined from a count of browsed and unbrowsed twigs on a plot, then expressed as a percent of total production. The twig-count method has proved as accurate as the laborious and destructive clip-and-weigh method and nearly as rapid as the rather subjective weight-estimation method for determining production and utilization of deer browse.

Incorporation of several innovations of a technique for electronically measuring herbage yields gives accurate, rapid determination of the weight of vegetation at a sampling point. The instrument, which is called a hetrodyne vegetation meter, consists of a measuring head with 15 probes that are placed in the vegetation and a separate reading unit. The vegetation between the probes causes a shift in the radio frequency field that is proportional to the mass of the vegetation. Reading time for each sample requires only 10 to 15 seconds. Correlations between the instrument and clipped samples in the annual grass type of California ranged from 0.94 to 0.98--1.0 being perfect correlation.

c. Range condition and trend. Aging of juniper (Juniperus occidentalis) trees in Devil's Garden, the winter range of the California-Oregon interstate deer herd, has clarified a misunderstanding that trees are increasing to the detriment of more valuable forage. Many of the trees in this area are small; however, as determined by increment cores, small trees less than 1-inch stem diameter at breast height averaged 35 years of age. The major increase in juniper, therefore, appears to have occurred at least 20 years ago at a time when the Garden was in its poorest condition owing to extremely heavy grazing.

Detailed vegetation records have been obtained periodically since 1915 on subalpine ranges on the Wasatch Plateau in Utah, and provide a reference for understanding time and sequence of succession. Plant cover increased following complete protection or reduction in livestock numbers. In the area once classified as a Penstemon-Achillea community, Rydberg penstemon (Penstemon rydbergii) is still a dominant species, both in an exclosure and on adjacent grazed range, but the undesirable western yarrow (Achillea lanulosa) remains as one of the major species only on the grazed area. Letterman needlegrass and sweet sagebrush (Artemisia discolor), species used relatively little by sheep, have increased on the grazed range. In contrast, subalpine needlegrass, Richardson geranium (Geranium richardsonii), and showy goldeneye (Vigueria multiflora), all relatively palatable to sheep, have increased in the exclosure. In a Chrysothamnus-Stipa community, less pronounced changes have occurred. Letterman needlegrass increased under grazing, whereas Douglas rabbitbrush (Chrysothamnus viscidiflorus) decreased.

Knowledge of the variation in vegetation and soil characteristics of mountain grasslands is furnishing a better basis for management. In central Idaho, maximum herbage production averaged 1342, 1486, and 1918 pounds per acre (air dry) on soils derived from basalt, granite, and sedimentary parent materials, respectively. Maximum basal cover of the vegetation on sites representing the three soil parent material groups ranged from 24 percent (basalt) to 33 percent (sedimentary). Soil characteristics positively correlated with basal cover of vegetation included soil depth, water holding capacity, and bulk density. The use of ordination techniques in analysis of the vegetation indicated a lack of species similarity in these grassland types. This suggests great ecological amplitude for the dominant Idaho fescue, and the existence of numerous ecotypes which complicate management.

Significant changes in herbage composition of Thurber fescue range were produced by cattle grazing under three different intensities of use on Black Mesa in western Colorado. Utilization of Idaho fescue, the most important forage producer on six range units (each intensity replicated), average 21, 35, and 49 percent herbage removal during a 6-year period. Grasses increased 57 percent under the lightest use, 47 percent under intermediate use, and 38 percent under the heaviest use.

RM

Forbs on the other hand, increased 22, 56, and 83 percent under the grazing treatments from lightest to heaviest. The proportion of grass herbage produced by Thurber fescue, a climax dominant, has declined under all treatments while the proportion of Idaho fescue has increased 3 percent under the lightest use, 8 percent under the intermediate rate, and 18 percent under the heaviest rate of grazing.

During the first 5 years of a proposed 20-year study, hydrologic and biotic characteristics of eight watersheds in the salt-desert shrub type of western Colorado changed relatively little. Aimed primarily to determine and compare the response of plant cover, infiltration and runoff, sedimentation, and small mammal populations on grazed and ungrazed watersheds, this study in western Colorado is a cooperative undertaking of five Federal agencies. In brief, watershed cover decreased slightly under dual use by cattle and sheep in the winter and increased slightly under no use. Small mammal populations were generally unaffected by grazing treatment.

The immediate effects of tractor logging were of major consequence to the forage resource on forested rangelands of the Pacific Northwest. Disturbance of soil to more than 1-inch depths occurred on 15 percent of tractor logged areas and resulted in severe losses of grasses and grass-like plants because of their shallow roots.

3. Livestock Grazing Practices

a. Native ranges. Well regulated, supplemental feeding has increased income from cows grazing pine forest ranges in Louisiana. Each cow was fed 375 pounds of cottonseed cake from October until May, along with salt and steamed bonemeal yearlong and a small amount of hay in late winter. Prior to the supplemental feeding, calf crops averaged about 45 percent and calves weighed less than 300 pounds at weaning time. Under the feeding program, calf crops were raised to 83 percent and weaning weights to 433 pounds. Market value of the calves averaged about $3 more per cwt. than for open range calves of similar age. Feed and veterinary costs averaged $22.46 per calf; returns which were available for labor, interest on investment, and profit averaged $67.64 per calf--several times above the level of return for most range herds.

Forage on pine-wiregrass ranges must often be supplemented to offset deficiencies in protein, phosphorus, and calcium, especially as forage matures; however, requirements of cattle grazing forest range may be satisfied more economically by access to improved pasture than by a protein meal supplement. In southern Georgia, average monthly mineral consumption of cows grazing forest range only, increased gradually from 4.50 pounds per cow in March to 11.47 pounds per cow in October, whereas consumption by each cow grazing forest range plus improved pasture averaged 4.74 pounds in March and then increased to a high of 4.81 pounds in October.

The effects of several factors on cattle distribution were studied on the Cache National Forest in northern Utah. Cattle use of grass was increased by applications of both fertilizer and herbicides. Although cattle did not seek out the treated areas, they used them readily after having been driven to the areas. Fencing mountainous areas into smaller units increased utilization on all slopes. As utilization by cattle increased on bottomlands from 35 to 90 percent, use on adjacent 25 percent slopes increased from 9 to 24 percent; on slopes of 40 percent, use increased from 5 to 15 percent; and on slopes of 55 percent, use increased from 3 to 14 percent.

No significant differences in animal gains have been obtained between rotation and continuous systems of grazing on cheatgrass range in Idaho. The general objective of management here is to utilize effectively the present "annual type" forage while encouraging conversion to more desirable perennial vegetation. In three years, gains of young cattle during a 7-month grazing period averaged 1.5 pounds per day. Gains were highest during late spring (2.04 pounds per day) then progressively declined through the summer and fall to 0.84 pounds per day.

Deferred-rotation and seasonlong grazing systems on Starkey Experimental Forest and Range of eastern Oregon have shown interesting treatment responses after 6 years. For example, cows have consistently gained more on units grazed heavily throughout the season than their counterparts on deferred-rotation units. Gains of cows and calves at moderate and light rates of stocking have been the same regardless of system. Although herbage production of all species shows no conclusive trend for either system of grazing or intensity of use, responses of certain individuals are interesting: bluebunch wheatgrass (Agropyron spicatum) production was higher with the heavy intensity of deferred-rotation grazing but at a moderate intensity of grazing production was similar for both systems; onespike oatgrass (Danthonia unispicata), however, increased an overall average of 25 percent with deferred-rotation grazing versus a 15 percent decrease under seasonlong grazing; furthermore, losses in litter have been significantly greater under the seasonlong system. These differences in species response to systems and intensities of grazing demonstrate the complexity of managing these ranges to maintain satisfactory vegetation conditions while allowing maximum livestock production.

b. Improved ranges. At Ephraim, Utah, where bulbous bluegrass (Poa bulbosa) and crested wheatgrass (Agropyron cristatum) were seeded together, the latter species has largely died under heavy grazing, but bulbous bluegrass has maintained similar yields on pastures grazed by sheep at 55, 65, and 80 percent utilization. However, yields of bulbous bluegrass have fluctuated greatly; high yields are associated with relatively high precipitation in the fall and low yields with dry fall weather. Where utilization has been less than 65 percent, yields of crested wheatgrass have fluctuated less from year to year than yields of bulbous bluegrass.

On the Santa Rita Experimental Range in southern Arizona, mesquite control results in increased grass production because of removal of competition by mesquite for soil moisture. Where mesquite had been completely controlled 14 years earlier, grasses produced 1,526 pounds per acre at an elevation of 4,100 feet. At the same elevation, where mesquite competition had not been controlled, production averaged only 339 pounds per acre. On a site 1,000 feet lower in elevation and with less rainfall, grasses produced 636 and 59 pounds per acre on mesquite-controlled and mesquite-infested areas, respectively.

RM

Reducing hardwood overstory in the Ozarks by spraying with 2,4,5-T increased total herbage production from less than 50 pounds per acre before treatment up to 1,800 pounds in the fifth growing season. However, this increase was mainly grass, sedge, and forb species of only fair forage value. Herbage production on plots seeded to native forage grasses ranged from 2,000 to 4,000 pounds per acre. Fertilizer increased production on all plots and appeared to promote better seedling establishment of native species. The possibilities of increasing forage production to this degree is important to the small farmer-livestock operators of the region.

Evaluation of clay pellets as a vehicle for seed application is underway at several sites in the Rocky Mountains. Preliminary results indicate small seeds, such as those of lovegrasses (Eragrostis spp.) and timothy (Phleum pratense), generally show higher germination rates (up to 96 percent) in pellets than large seed such as those of Lincoln smoothbrome (Bromus inermus), which sustain a high breakage rate during pellet manufacture. The viability of some seed, particularly those of legumes, is evidently lowered by too much moisture in the clay pellet. Results of seeding trials will not be available until later this year following summer rains.

Integration of seeded ranges with native pine-bunchgrass ranges promises to be a practical and profitable livestock management system in the Front Range of the Rocky Mountains. In 1963, calves raised part-time on native range and part-time on ranges seeded with Russian wildrye (Elymus junceus), crested wheatgrass (Agropyron desertorum), and Sherman big bluegrass (Poa ampla) weighed an average of 17 pounds more per head when weaned than those raised on native range alone; the latter is the practice commonly followed in the area. Based on 1963 prices, each calf raised under the integrated grazing system was worth $4.10 more than one from native range. Sherman big bluegrass was primarily responsible for the additional weight gain. Unweaned calves that grazed this species from October 15 to November 15 gained 1-3/4 pounds daily compared to 1-1/4 pounds for calves that grazed native bunchgrass range at the same time. Cows gained 0.73 pounds per day on bluegrass from October 15 to December 30, but lost 0.78 pounds per day on native range.

For monthlong spring grazing under New Mexico conditions, optimum utilization of crested wheatgrass appears to be between 65-70 percent, based on weight of herbage produced by the end of the grazing period. Under this use, the seeded stand was maintained in productive condition and weight gains of cows, calves, and yearlings were satisfactory. Regrowth following grazing is believed to have enabled plants to regain vigor after having been grazed so closely. The critical shortage of native forage in the spring in northern New Mexico could be alleviated by more extensive planting and use of crested wheatgrass for cattle grazing.

A combination of range fertilization with sulfur and nitrogen plus grazing when the forage is green increases grazing value of annual-plant range in California. Although fertilization increased herbage yields, repeated grazing after the forage had matured gradually lowered its grazing value by decreasing the percentage of soft chess (Bromus mollis) in the stand and increasing ripgut brome (B. rigidus). The latter species provides good forage when green but it becomes less desirable when dry.

4. Burning for Range Improvement

As a basis for converting annual-type vegetation in southern Idaho to more valuable perennial forage species, effects of herbage removal by burning and clipping were studied on cheatgrass range. Bottlebrush squirreltail and needleandthread (Stipa comata) suffered reductions in yield one year after burning and/or clipping treatments at monthly intervals between May 15 and September 21. May and June burning treatments were more severe on squirreltail while yields of needleandthread were reduced most by treatments applied in July and August. Clipping was less damaging than burning in every season.

Ranchers burn south Florida rangeland progressively from fall until the rainy season in the spring to improve forage quality, quantity, and availability. However, effects of burning are not fully known. Studies to date show that the month a range is burned exerts a marked influence on subsequent plant response. During the two-month period immediately following a fire when wiregrass forage is most nutritious, yields of herbage were two to four times greater on ranges burned in March and May than on those burned in October and November. Moreover, seed production by pineland threeawn (Aristida stricta) was stimulated greatly by burning in May. Coupled with less frequent burning, the addition of rock phosphate can increase nutrient quality manyfold.

Excessive accumulation of litter causes stagnation of plants on native prairie, and occasional burning benefits this type of range. Herbaceous plants on recently burned areas in Iowa started growing 2 to 3 weeks earlier in the spring, developed faster, and matured earlier than plants on unburned areas. Flower stalks of forbs and grasses were more abundant and taller on burned areas until the third growing season after the fire. Higher soil temperatures resulting from litter removal and release of phosphorus with burning were primarily responsible for the earlier development and maturation of the vegetation.

5. Range Pest Influences and Control

Large populations of pocket gophers (Thomomys talpoides wasatchensis) were reduced about half by an intensive poisoning program (by using 1080-poisoned grains) on Cache National Forest in Utah. Continued treatment for 3 successive years kept the population approximately at the same level as obtained the first year of control. After a single year of no control, gopher numbers doubled and were about as large as they had been prior to treatment. Apparently, a more effective method than direct poisoning is needed if gopher control is to be practical on rangeland.

Mountain pocket gophers (Thomomys talpoides) make use of the snowpack for travel and feeding on above-ground vegetation in the winter. They also deposit cores of soil in the pack as they clean and extend their below-ground burrow systems. Snow tunnels on Black Mesa in western Colorado have been observed from ground line to as high as 18 inches in the snowpack, which is usually from 4 to 5 feet thick. Within this zone of gopher activity temperatures ranged from 31° to 33° F. at the ground line; at 18 inches up in the pack the temperature range was from 28° to 31° F. Temperatures during this period in burrow systems 4 to 8 inches below ground varied from 32° to 44° F. Knowledge of pocket gopher activities and habitat is necessary for evaluating their effects on vegetation and soils and in furnishing supplemental information for development of control measures. The success of indirect control in reducing the population of this species of pocket gopher by changing the habitat (by application of herbicides) from one predominantly forbs to grass has been previously reported.

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D. WILDLIFE HABITAT MANAGEMENT

Problem

Wildlife habitat supplies food, cover, and water and is the key to optimum game and fish production. Management of the habitat is complex. Each kind of animal has rather specific habitat requirements, and these must be balanced against requirements for production of water, timber, and forage for livestock. Demands for all uses of forest and related rangelands are increasing, and serious situations have arisen, often with severe impacts on game and fish habitats; consequently, wildlife habitat research is needed to develop the most effective and harmonious management practices for the various vegetation types and associated animal use.

Specific phases of the problem are: (1) to devise methods for restoration of deteriorated habitats or improving those naturally unproductive; (2) to develop and evaluate management systems through studies on the nature and degree of competition between wildlife and livestock, effects of timber production and cutting practices on forage for wildlife, and reciprocal effects of forage production and grazing use on timber reproduction; and (3) to determine the effects of land use on fish habitat and develop ways to improve game and food fish habitat and food supplies such as by regulation of shade and water temperatures, by manipulating riparian vegetation, by stabilization of streambanks, and other measures.

USDA and Cooperative Programs

This is a continuing, long-term program of both applied and basic research at numerous locations in the various plant-animal communities throughout the United States. It involves interrelations of wildlife and livestock and integration of timber and forage values to allow optimum production and utilization of each. Studies are conducted in cooperation with various State and Federal agencies such as fish and game departments, agricultural experiment stations, Fish and Wildlife Service, Soil Conservation Service, Agricultural Research Service, Bureau of Land Management, and in some instances with sportsmen associations, private companies, or individuals.

The Forest Service scientific effort involved in this research totals approximately 26 man-years.

Program of the State Agricultural Experiment Stations

Research on wildlife habitat management is being conducted by two states. Forest areas with different management histories are under investigation to determine their utilization by ruffed grouse. Special attention is being given to the selection of forest types and local conditions favorable for drumming, nesting, and brood development. Radio-positioning techniques are used to obtain records of bird movements, use of cover and foods taken. Data are being gathered on sex and age distribution and mortality of grouse populations.

The effects of forest fires and human inhabitants on vegetation and game populations also are under study. Water holes have been constructed and grass and legumes have been seeded on fire trails throughout a forested area to provide conditions favorable for the development of wild turkeys and other wildlife. Nest boxes have been provided for squirrels to determine the influence of this management practice on population increase.

The research effort devoted by these two states to wildlife management research is 2.0 man-years.

Progress--USDA and Cooperative Programs

1. Wildlife Habitat Improvement

Research in Utah's Great Basin area has improved the prospects for successful restoration of game ranges in the juniper-pinyon belt. This is mainly of benefit to mule deer. The chief method of improving this range involves reducing tree stands by dragging the area with a heavy chain attached between two tractors, followed by airplane broadcast seeding of desirable food plants. Chaining and seeding costs averaged from $5 to $7 per acre, and seeded stands were 80 to 90 percent successful. The more complete the seed coverage the better the forage stand that developed. Promising species which are adapted for seeding lower sites in the juniper-pinyon belt, which are often critical for deer in midwinter, include several shrubs (big sagebrush (Artemisia tridentata), black sagebrush (A. nova), rubber rabbitbrush (Chrysothamnus nauseosus), fourwing saltbush (Atriplex canescens), antelope bitterbrush (Purshia tridentata), Stansbury cliffrose (Cowania stansburiana), winterfat (Erotia lanata), and desert peach (Prunus fasciculata); several species of penstemon (Penstemon spp.) and German iris (Iris germanica); and several grasses (fairway crested wheatgrass, desert wheatgrass, Russian wildrye, bulbous bluegrass, and bluestem wheatgrass (Agropyron smithii)).

Browse for deer, antelope, and livestock in western New Mexico can be increased by seeding fourwing saltbush (Atriplex canescens). It is high in protein content, a nutrient often deficient in dried and weathered grasses that are commonly the chief source of available forage. Seedbed preparation as by disking, to remove competition of undesirable plants, is recommended. Although plants were successfully established by drilling on an unprepared seedbed, the resulting stands were much poorer than those on prepared seedbeds. Tests indicated temperatures for germination were most favorable between 42° and 58° F. and neither soaking the seed to remove chlorides nor dewinging increased germination. Germination and growth of seedlings were related to seed source, and maximum growth was obtained in a sandy loam soil.

In a test of animal repellents, both Z.I.P. (zinc dimethyl dithio carbamate cyclohexylamine complex in polyethylene polysulfide adhesive) and TMTD (tetramethyl thiuram disulfide) prevented practically all overwinter browsing of sprayed twigs of chokecherry (Prunus virginiana) and aspen (Populus tremuloides) on two winter deer ranges in the Black Hills. From 15 to 25 percent of the twig length of unprotected shrubs was browsed by deer. If the repellents are effective in reducing browsing of these and other shrubs for extended periods, they may eliminate the need for costly cages and fences in future experimental plantings.

Planted stock of introduced species, including desert bitterbrush (Purshia glandulosa) and cliffrose, have made growth equal to that of the native antelope bitterbrush in southern Idaho. Some plants of these introduced species reached 13 inches in height in 2 years. Seedling establishment after 2 years has been 62 to 79 percent on grazed range. The introduced species deserve additional evaluation for possible use in revegetating depleted deer winter range.

There apparently is little hope for rapid increases in antelope bitterbrush (Purshia tridentata) merely by eliminating deer use. Studies in Idaho and Oregon related to natural reproduction of bitterbrush have shown no new plants have become established, either inside or outside deer exclosures (protected for more than 8 years). Established plants increased in size but, in general, changes in plant cover have been minor.

Fertilization of four soils on which true mountain-mahogany (Cercocarpus montanus) commonly grows in the central Rocky Mountains resulted in impressive productivity increases in greenhouse trials using barley. With additions of NPK, yields of barley were increased 4 and 5.5 times on two soils developed from limestone, and 8.5 and 20 times on less fertile soils developed from arkose and granite, respectively. Germination and early growth of mountain-mahogany from a common seed source also was influenced by soil parent material. If specific factors that are responsible can be discovered, it may be possible to establish mountain-mahogany or increase the abundance of this important big game browse plant on sites that now are unproductive.

With the decline in hemlock throughout much of its commercial range in the Northeast, the habitat of ruffed grouse has largely disappeared. Extensive large openings as well as orchard-type and pole-timber hardwood stands are potential sites for habitat improvement with planting of 3-0 hemlock seedlings. Survival and height growth of this species, which is unequaled in cover value for grouse, were best in orchard-type stands on north-facing slopes. No advantage was apparent in preparing the planting spot by removal of competing herbaceous vegetation.

2. Integration of Wildlife, Livestock, and Timber Production

Wildlife habitat research in the Southwest is emphasizing forest, woodland, and shrubland (chaparral and sagebrush) habitats where land management activities affecting wildlife are intense. Comparative use of selectively cutover forests and natural openings in a ponderosa pine forest of Arizona as measured by accumulated pellet groups indicated that: (a) deer use timbered areas and openings about equally, whereas elk and cattle prefer openings; (b) beyond 700 to 800 feet from the forest edge, elk and deer use of openings was less than use of forest borders; cattle use of openings was higher than that of the forest edge; (c) numbers of elk and cattle droppings were associated with abundance of perennial grasses, whereas deer pellet density was associated with forbs. In another study of elk and deer habitat in pinyon-juniper woodland in southern New Mexico, it was found that: (a) shrub density increased with tree density up to about 200 trees per acre; in denser tree stands shrubs were less common; (b) some woodland areas without understory shrubs are essential for big game shelter; (c) pellet groups from both deer and elk were most abundant on northeastern exposures where shrub production is highest; and (d) deer and elk use was unaffected by slopes up to 40 percent provided suitable forage and cover were present.

In the Southeast evaluation of numerous sites as to quantity, quality, distribution, and degree of use of deer browse in relation to forest types, ages, and stand conditions is providing information and clues useful in habitat management. For instance, the highest production of deer browse in Georgia was in the piney woods where small saw timber stands produced an average of 54 pounds per acre, 29 pounds of which were considered to be desirable species and the remainder classed as emergency or "stuffing" foods. Hardwood sites were lowest in the production of desirable browse, averaging less than one pound in a 39-pound total production per acre. Such information collected on specific deer ranges together with regulating effects of cutting practices is needed by the forest manager for keeping deer herds in balance with the forage supply.

The relative preference by deer for eight herbaceous species has promise for improving deer habitat in the Southern Appalachians. Of two clovers and six grasses that were available, consumption of clover was 3.5 times greater than the grasses. However, utilization of the grasses was noticeable in the fall and exceeded that of the clovers during late winter and early spring. Red clover (Trifolium pratense), Ladino clover (T. repens), orchardgrass (Dactylis glomerata), and shade fescue (Festuca rubra var. heterophylla) were most promising species due to the large amounts of forage produced and utilized.

In assessment of the productivity of quail habitat in the piney woods, samples of the surface inch of soil provide a convenient means of evaluation. It was found that more than 14 pounds of seeds of partridgepeas (Cassia fasciculata), a favored quail diet, were produced on the better sites in contrast to less than 1 pound per acre where quail production was low.

Abundance of deer forage is related to the cutting system employed in east Texas pine-hardwood forests. Yield was 1,600 pounds per acre, 11 years after clear cutting; 853 pounds per acre after a selection cutting; 727 pounds after a shelterwood cutting; and 426 pounds where no cutting had been made. After harvesting, tree basal area averaged 26, 76, 76, and 96 square feet under the four conditions. Regardless of cutting treatment, however, the midstory crown cover strongly influenced forage growth. In the absence of a well-developed midstory, considerable light penetrated the dominant crown and forage yields were often high even though crown cover of tall pines approached 40 percent.

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III. FOREST PROTECTION RESEARCH

A. FOREST FIRE

Problem

Wildfires are a constant threat to our forests and wildlands, and frequently to the lives and property of suburban and rural residents. They represent a tremendous drain on both natural resources and public funds.

The estimated total direct cost of wildfire control in the United States is currently $150 million and continuing upward. Nationwide, forest fires number over 100,000 a year and burn over about 5 million acres of land. Both number of fires and burned area vary somewhat from year to year depending upon the length and severity of the fire season. Although recent years have shown no meaningful downward trend in number of fires, the area burned shows indications of decreasing slightly.

For a number of years fewer than 5 percent of the total fires that start have been causing 90 percent of the cost and damage from fire. These are the runaway fires. After they become large, high costs and damage are inevitable. But most could be controlled at small size if the potential for runaway behavior could be identified in advance. The kind of knowledge that will enable fire control specialists to make such identifications is accumulating, but much remains to be learned. Meanwhile the development of fire suppression techniques has to proceed on the basis of limited knowledge. These interim fire fighting methods are satisfactory for controlling the average fire. Too frequently they are not adequate for controlling the more aggressive fires, those which result in the high damages and costs. Development of the more exacting techniques of control that such fires require, depends first on ability to identify them in their very earliest stages. This can only be achieved through continued intensive research.

Of equal importance is the opportunity for major reductions in fire losses through improved fire prevention measures that span a wide range of multiple-use forestry activities. Improved practices in cultural treatment of forests, logging and engineering work, programmed hazard reduction, "shotgun" and specific contacts with forest users, that are tailored to the measure of their impact on numbers of fires require accelerated prevention research and the rapid application of results to all areas of forest management and utilization.

Only slightly less urgent is the need to develop safe and effective techniques for using fire purposefully on wildlands as a direct protection measure and for other land management purposes. In recent years, "brush" fires on unmanaged wildlands have accounted for much of the fire bill. As populations increase these lands are becoming more and more important in our national economy -- as watersheds, recreation sites, ranges for wildlife, and even residential areas. Prescribed fire offers much potential as a tool for land management plus a means for more effective protection at less cost.

USDA and Cooperative Programs

The Forest Service has a continuing long-term program involving numerous disciplines in the physical, biological and social sciences engaged in both basic studies and application of known principles to the solution of wildland fire problems. The

research is conducted at the Macon, Georgia; Missoula, Montana; and Riverside, California, Forest Fire Laboratories as well as at projects in Fairbanks, Alaska; Portland, Oregon; Berkeley, California; Fort Collins, Colorado; Flagstaff, Arizona; Salem, Missouri; St. Paul, Minnesota; Upper Darby, Pennsylvania; Asheville, North Carolina; and Alexandria, Louisiana.

Weather and fire behavior research at the three fire laboratories and at Portland, Salem, Berkeley, and Alexandria is cooperative with the Department of Defense, Weather Bureau, National Science Foundation, National Bureau of Standards, State conservation agencies, universities and other research institutes. Fire prevention studies relating to man-caused fires at Riverside, Berkeley, and Alexandria are cooperative with the University of California, the University of Southern California and the Universities of Louisiana and Mississippi, respectively. Lightning prevention research at Missoula is cooperative with National Science Foundation, Weather Bureau, Montana State University and University of Washington. Fire control systems and methods research at all locations is cooperative with State and local conservation agencies, universities, field offices of other Federal agencies, private landowners, and private industry. Use of fire studies are cooperative with State and local conservation agencies, Weather Bureau, universities, and public and private land managers.

One fire behavior study is conducted by Instituto Nacional de Tecnica Aeronautica Esteban Terradas, Madrid, Spain under PL-480 contract.

The current Federal scientific effort devoted to this research is 70 professional man-years. These are divided by subject matter approximately as follows: 21 to weather and fire behavior; 7 to fire prevention; 36 to fire control systems and methods; and 6 to fire use.

The Forest Service is the only Federal agency which conducts forest fire research. In addition, the Forest Service, at the Forest Products Laboratory, and several other Federal agencies conduct or sponsor research on fire problems relating to missions other than forestry. All these groups, in common with the Forest Service, have interest in basic laws and principles of combustion and extinguishment. Work is coordinated closely through several mechanisms. The Committee on Fire Research of the NAS-NRC assumes national leadership in this process. Some States and universities conduct short-term forest fire studies, though mostly through cooperative agreements with the Forest Service.

No major lines of work were terminated during the year.

Program of State Experiment Stations

Nothing to report.

Progress -- USDA and Cooperative Programs

1. Weather and Fire Behavior

a. Fire physics. Methods have been developed at Macon, Georgia for producing highly-stable model fire whirlwinds in the open air. These fire whirls can tolerate light air movement and have little or no tendency to wander, thus permitting detailed study of their structure.

Studies of wood crib fires in California show that as much as half of the radiated energy emanating from such fires originates from the glowing combustion of the embers. The rate of fire travel through the cribs was shown to be little influenced by radiation emanating from the impressive flame zone above the fuel structure.

b. Fuel Moisture. Forest flammability changes with moisture in both live and dead materials. Studies in California indicated that the moisture content of the foliage of whiteleaf manzanita varied with elevation during the growing season and at any given elevation was correlated with soil moisture. Ponderosa pine needle foliage remained fairly constant throughout the year.

A study of moisture sorption characteristics of hardwood leaves at the Southern Forest Fire Laboratory indicated very little difference in equilibrium moisture content of the seven species tested. Equilibrium moisture content (EMC) is the value toward which the moisture of a sample changes when exposed to air of known relative humidity. Results showed that in general the EMC's for leaves are higher than those for wood.

c. Rate of Spread. Combustion studies at the Northern Forest Fire Laboratory indicated that flame depth and residence time in beds of pine needles appear to reach a maximum when fuels have about 10 percent moisture content. A formula was developed for predicting the rate of spread in either Ponderosa or white pine litter in the absence of wind.

Tests at the Southern Forest Fire Laboratory, in which wood cribs of identical moisture content, size, and construction were burned under varying wind speeds, indicate a linear relationship between rate of fire spread and wind speed, when wind velocities ranged between 3.5 and 13.5 feet per second. Design of the cribs permits wind to blow through the crib as well as over and around it. This probably accounts for the linear rather than the curvilinear relationship observed when flat compressed beds of pine needles are burned.

d. Meteorology. A recent study has shown that polar air masses may result in severe burning conditions for a much larger portion of the day than do typical air masses in the Ouachita Mountains near Hot Springs, Arkansas. Polar air is generally drier, but an interaction with topography also appears to be important. Between 8 p.m. and 8 a.m. temperature was observed to remain much higher and relative humidity much lower on ridges than in valley bottoms. In tropical air, ridges and valleys experienced about the same diurnal fluctuations.

In the Pacific Northwest the temperature and relative humidity in a mixed layer of air vary in a regular way with change in elevation. Two charts were developed to permit extrapolation of observed values of temperature and relative humidity to other elevations in the vicinity.

Two studies north of San Francisco Bay showed that when the daytime sea breeze is shallow, it becomes warm a short distance inland and its front could affect forest fire behavior adversely.

Wind speed 3 feet above ground level in pine forests of the Southeast was found to average about one half the wind speed as measured at 20 feet at an open fire danger station. Ratios of wind speed (20 feet) in the open to that in the forest (3 feet) varied from a low of 1.5: 1 to a high of 5:1, depending on stand density and height.

A study of critical fire weather patterns and their relationship to synoptic patterns and to topography is in progress at the Pacific Southwest Forest and Range Experiment Station. One comprehensive study which relates critical fire weather periods to associated weather maps has helped identify the synoptic weather types which create critically high fire danger in different regions of the United States. It will be especially helpful to fire weather forecasters.

e. Fire and Environment. Techniques are being developed in California for measuring the characteristics of mass fire - fire burning simultaneously over an extensive area. Several findings to date are contrary to generally accepted theoretical concepts. For example, commonly applied vector analysis to explain convection column behavior in a wind field is shown to be inappropriate because wind does not blow directly into the windward side of the convection column. In the study of fires confined to a finite area, it has been found that the flame region and lower part of the convection column, at least, act as a solid obstruction to wind flow. Consequently, air flow around the fire bears a marked similarity to flow around any solid object in a moving fluid, with eddies and turbulence developing on the lee side. This is undoubtedly true of moving front as well as stationary fires.

Oxygen deficiency in hot fires permits the development of strong concentrations of noxious gases within the fuel bed and combustion zone. Concentrations of carbon monoxide exceeding 5 percent and carbon dioxide exceeding 9 percent have been measured.

In fires of any appreciable size, the convection column is not a single rising column of hot gases. In the flame zone and for some distance above, the column appears to be highly turbulent with both updrafts and downdrafts. In this area, the column is made up of several smaller convection areas or "hot spots"

2. Fire Prevention

a. Man-caused fires. Large numbers of signs are used in forest areas to convey fire prevention messages. A cooperative study with the University of Southern California using a captive group of university students has developed a technique permitting quantitative measurement of the effectiveness with which a particular sign elicits a desired response in the viewer. In trial tests, signs that combined a short message with an illustration have been found quite specific in this respect while unillustrated signs with longer messages are not. The system is now ready for pilot testing in selected problem areas to determine which of existing fire prevention signs are paying their way and which are not. New types of signs are also to be tested.

b. Lightning-caused fires. Lightning ignites forest fuels some 10,000 times each year in the United States and so is an important ignition source.

Three years ago Project Skyfire determined that ground-based silver iodide generators cannot be relied upon to produce significant concentrations of crystals suitable as ice-forming nuclei at thunderstorm cloud base levels. New higher capacity generators were then designed for aircraft mounting such that release could be made at cloud base altitudes. Using this aerial cloud seeding technique, there is encouraging evidence that lightning reduction may be possible. The actual rate of production of crystals still falls short of the theoretical rate, however, indicating the need for further refinement or a completely new production technique.

An exploratory study was made into the possibility of predicting maximum lightning fire occurrence on the basis of 30 day extended forecasts of temperature and precipitation. Results were encouraging.

Prototype lightning direction finders were tested in Montana. An analysis of 30,000 sferics 1/indicated a high degree of correlation between sferics activity and known lightning storm locations.

The known compression of the lower atmosphere over the poles relative to that over the tropics has given rise to speculation as to the altitudinal zones in which thunderstorms occur in far northern climates. Last year in interior Alaska, 46 thunderstorms several of which produced lightning were observed to have tops ranging between 14,000 and 30,000 feet and bottoms between 4,800 feet and 7,300 feet in altitude. These compare with tops often above 40,000 feet and bottoms 10,000 to 15,000 feet often observed in the temperate region of the United States.

3. Fire Control Systems and Methods

a. Detection. Continuing tests in Montana of an airborne infrared scanner indicated a very high probability of detection for fires of 3 to 6 foot radius in fir and pine stands at verticle angles of 0° to 50°. In Engelmann spruce there was an acceptable detection probability when the fire radius reached 12 feet. The 50° angular limit indicates that dependable detection over a 2-mile wide strip can be achieved by scanning from height of 4500 feet above the landscape.

b. Fire danger rating. A National Fire Danger Rating System Handbook was prepared. The material covers the location, installation, operation, and maintenance standards for the recently completed spread phase of the National system. Spread index tables were developed in final form. Several U. S. Forest Service Regions and many States are in the process of converting to the National system. Studies carried on at many places provided the fire control organizations with a basis for applying the new spread index values in their fire control plans, including preparedness and manning guides.

c. Presuppression. Studies of conflagration barriers and management for conflagration control in California showed that as an independent operation costs of fuel breaks in timber country may run over $300 per acre when installed. However, when programmed with normal land management jobs, only a small additional outlay is required. Breaking up large wild land areas with fire barriers consisting of fuel-breaks and natural barriers may thus be economically feasible. In a related study, living ground cover of a native perennial, such as bear clover, tended to maintain favorably high fuel moisture levels on fuel-breaks even though tree crown cover was reduced as much as 60 percent.

The use of fire retardant chemicals for season-long fire-proofing of roadside vegetation is promising, but solubility of the retardant residue is a yet unsolved problem.

Use of a chipper for slash disposal in a young timber stand in California showed that chipping compared with alternative disposal methods in cost, and resulted in better disposal. It was cheaper to chip dry slash than green slash.

1/ Very-low-frequency electromagnetic radiation from lightning strokes.

Observations, after one year of a five year study, indicate that application of a commercial chemical slash dissolver has resulted in greater compaction and some disappearance of fuel in the 0-1/4 inch size class in pine slash.

Two studies relating to presuppression were conducted at the Operations Research Center, University of California. One, concerned with determining the best location of stand-by crews, defined procedures for determining these locations. The other examined control line productivity by hand-crews under several simple tactics and included effects of crew size, fatigue and number of shifts per day. The need for better data on fire line construction productivity was demonstrated.

Using crown weight measurements of individual trees, a method was developed in the Lake States to predict the amount of tree-crown fuel in plantation stands that vary by age, site, and stand density. The proportion of needles to the total crown weight was determined, and also the quantity of slash fuel that would result from various levels of pulpwood cutting.

d. Suppression. Tests of the effectiveness of several industrial gums and two clays to thicken water and ammonium phosphate solutions as Macon, Georgia showed less gum material needed and mixing generally easier, but thickening with clays is much less expensive.

Calibration trials of chemical fire retardants with a TBM aerial tanker in the Southeast indicated that the type and density of forest canopy determine the volume of drop required to give satisfactory penetration and ground coverage. Required volumes range from 200-300 gallons over open areas to more than 440 gallons over hardwood stands in full leaf.

Trial drops in the Southeast with a TBM aerial tanker from altitudes of 100-150 feet showed that foam solutions reacted with entrained air to produce foams with expansion ratios up to 40:1. However, the foam stability was poor and excessive drift occurred when winds exceeded 5 m.p.h.

Tests in California indicate that late model helicopters with new helitanks can deliver accurately as much fire retardant as most fixed wing air tankers at potentially lower costs.

Operational field tests have also confirmed earlier laboratory and field studies and showed that in aerial application viscous solutions of diammonium phosphate (DAP) are more effective than other known fire retardants.

The Model 2 Michigan Sand Caster, a machine designed to cast as much as 4 cubic yards of earth per minute, was tested extensively in Michigan, Georgia, and Florida. Tests showed that sand cast in sufficient quantity is capable of extinguishing flames. Used in advance of a fire, it increases the fuel's resistance to ignition and reduces both fire intensity and rate of spread. Operational difficulties were encountered that have been corrected in a later model.

Wire screens are proposed by the Southern Forest Fire Laboratory to protect fire plow operators against radiant heat. Screens have been shown capable of reducing transmitted radiant heat in proportion to their metal area.

4. Fire Effects and Use

a. Thermal effects of fire. From work done in the Southeast relating to the physical mechanisms of fire injury, it is possible to predict the effects of a given fire on tree stems.

Studies at Gulfport, Mississippi showed that mineral nutrition significantly affected the heat resistance of sweetgum and southern pine foliage. Reaction was not uniform, however, since the same mineral deficiency increased the resistance in some species and decreased it in others.

b. Prescribed Fire. Optimum fuel moisture conditions and relative humidities for hazard-reduction fire prescriptions have been identified in the Southeast. Satisfactory fuel moistures range from 5-14 percent (optimum about 8); relative humidities from 30-60 percent (optimum about 40). Strip head fires applied during the summer have been shown to be most effective in killing small understory hardwood. Single prescribed fires in loblolly pine stands on slopes up to 20 percent have not resulted in any appreciable soil movement.

A study on nearly a million acres in north Florida and south Georgia, for a 4-year-period, show that age of rough after prescribed burning has no major influence on wildfire occurrence. However, the differences in burn acreage, particularly between the youngest and the oldest roughs, were extreme. Virtually all of the burned area was caused by fires starting and principally burning in roughs older than 5 years.

c. Techniques of Burning. A chemical desiccation treatment is nearly as effective as mechanical crushing for getting crown consumption in prescribed burning Arizona chaparral, provided burning is done while leaves are attached. Chemical treatment to enhance flammability offers more opportunity than mechanical crushing for regulating the amount of litter consumed by intentional burning of Arizona chaparral.

Tests of a wind machine in slash burning in California indicated that although it speeds burning and permits burning on otherwise impossible days, the costs make it an impractical substitute for conventional methods.

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B. FOREST INSECTS

Problem

Insects are among the most destructive of all the agents affecting the forests of this country. Each year they not only kill, weaken, degrade, or reduce the growth of vast quantities of valuable commercial sawtimber but, also, of large volumes of smaller-size timber. During periods of outbreaks, which occur frequently in many parts of the country, losses are much more severe, often bordering on the catastrophic. Losses are not confined to timber alone: watersheds and wildlife habitats are impaired and fire dangers are increased. Insects also damage or destroy the seeds and cones of trees, thereby jeopardizing the success of seed orchards and natural regeneration programs; they infest browse plants on forest-related ranges, thereby lowering their carrying capacities for livestock and big game; and they damage or destroy huge quantities of forest products, such as logs, lumber, and pulpwood each year. More information is needed on the causes of forest insect outbreaks; on the development of long-lasting silvicultural and biological control methods; and on the development or improvement of chemical controls that can be applied economically and without undue hazard to fish and wildlife.

American forestry faces a crisis. Public concern about toxic and persistent chemicals requires that their use in forest protection and management be curtailed. This places our forests in jeopardy. And should it become necessary to completely abandon the use of chlorinated hydrocarbons, before we have substituted other prevention and control measures, our forests would stand fully exposed to immediate uncontrolled epidemic losses from insect pests and to accelerated losses from forest diseases and animals.

USDA and Cooperative Programs

The Department has a continuing long-term program involving forest entomologists, insect ecologists, insect physiologists, insect pathologists, microbiologists, and photo interpreters engaged in both basic and applied studies directed toward the development of safer and more economical and effective methods of direct and preventive control of forest insects. Research is underway at the 10 Forest and Range Experiment Stations, Forest Products Laboratory, and Beltsville, Maryland Forest Insect Laboratory. The program is cooperative with various universities, State Experiment Stations, industries, other Federal and State Agencies, and Canada Department of Agriculture. The University of Connecticut assists in studies of bacteria in insects; Brookhaven National Laboratory, in studies of male sterilization of the gypsy moth by gamma irradiation; New York State Museum and Science Service, in ecological studies of the gypsy moth; University of California, in studies of insects affecting seeds and cones of Douglas-fir; National Park Service, of lodgepole needleminers in Yosemite National Park; Ohio Agricultural Experiment Station, studies of the locust borer. Agricultural Research Service cooperates in introduction of insect parasites and predators from abroad.

PL-480 projects are underway in Finland, Poland, Spain, Yugoslavia, Pakistan, India, Brazil, Colombia, and Uruguay. Emphasis in most projects is on the identification, study, collection and shipment to this country of parasites and predators of important introduced forest insects.

The Forest Service scientific effort devoted to research on forest insects totals 85.5 man-years per year.

Several chemical companies supply materials for testing as systemics, and for control of wood products insects. Weyerhaeuser Timber Co. conducts research on insects affecting Douglas-fir. The University of Wisconsin studies plantation insects; University of Connecticut, the gypsy moth; and University of Michigan, borers in aspen.

Program of State Experiment Stations

The state agricultural experiment stations are engaged in a wide range of forest insect research problems.

Several southern State stations are contributing to a regional study (S-36) to determine the relation of Nantucket Pine Tip Moth attack on young pine to subsequent growth and yield and the effectiveness of parasites and predators as natural control agents. The usefulness of gamma radiation as a sterilization technique for control of Neodiprion fulviceps is being studied in the West. The biology and control of pine sawflies are being investigated at a number of States. A loss of vigor factor in a declining population has been noted. Methods of detecting bark beetle infestations and the association of fungi and the beetles are under study at several stations.

Seed and cone insects are receiving increased attention. Artificial rearing techniques are being studied and developed for a number of forest insect pests and parasites. The use of Bacillus thuringiensis Berliner in the control of the gypsy moth and fall cankerworms is being evaluated at two stations. Sex attractants and a parasite of the red pine scale are under investigation in the Northeast. A collection and enumeration of arthropods in forest litter is being made at one station. Several stations are studying aphid pests of conifers, for example: the effects of Balsam Woolly Aphid on wood anatomy and the ecology of the Pine Leaf Aphid. A number of stations are investigating methods of detecting forest insect outbreaks. Taxonomic studies are underway at several locations.

A total of 10.9 professional man-years effort is devoted to this work.

Progress - USDA and Cooperative Programs

1. Biological Control

It is the general consensus that populations of most native forest insects are held to sub-economic levels by their natural enemies, such as parasites, predators and disease pathogens. Even where outbreaks occur, populations sooner or later are brought back to normal levels by these agents, even though no direct control action is taken. Introduced insect pests may become extremely destructive because of the absence of natural enemies. Here, it is often possible to remedy situations by introducing these agents into infested stands from the native homes abroad of these pests. It has been found possible to secure control of some insects through interference with their reproductive capacities. Some biological control factors such as viruses and bacteria can be formulated into sprays and applied to control active infestations of certain insects. Generally speaking, biological control is cheaper, safer, and longer-lasting than conventional methods of insect control.

a. Insect parasites and predators. During the past 7 years, over 65,000 individual insect predators, representing 22 species, of the balsam woolly aphid have been introduced from abroad into the Pacific Northwest. So far, 5 of these have been successfully established; and two are showing promise in control. Neither of the

two has as yet demonstrated the capacity to reduce aphid populations to the point where tree killing is prevented, but the dispersal of both is increasing. To hasten their spread throughout aphid-infested stands, colonies are being collected in areas where they are established and released in new areas.

Over 12,000 adults of the beetle, Laricobius erichsonii, were released at mile intervals along the Black Mountain range in North Carolina in 1962. The beetle reproduced and overwintered on several of the sites where it was liberated. Follow-up studies will be made to determine the effect of these liberations on aphid populations in Fraser fir stands.

The life history of a new species of nematode, Parasitaphelenchus, which attacks the roundheaded bark beetle, Dendroctonus convexifrons, in the Southwest was tentatively determined. This nematode, which occurs in the body cavity of the beetle, is a polymorphic species, with the parasitic form bearing little resemblance to the free-living form. The latter is deposited in the egg galleries of the beetle within two weeks after it attacks a tree. The nematode attacks all immature stages of the beetle but does not reproduce within a beetle, each nematode entering as a separate individual. So far, this parasite is not known to seriously reduce the reproductive capacity of infested female beetles; however, massive infections might kill or sterilize them.

The larval stage of a predaceous beetle, probably Enoclerus sphegeus, appears to have played an important role in controlling an outbreak of the roundheaded bark beetle, Dendroctonus convexifrons, in the Southwest in 1963. Highest percentage reduction in brood populations occurred between May 20 and June 20 when feeding by the clerid was at its peak. High temperatures caused by direct solar radiation were also effective in reducing populations on the south side of trees.

The exact cause of the 1962-1963 decline of an outbreak of the spruce budworm in Colorado, which had been underway for 10 years, has not been determined, but it is known to have followed a greatly reduced deposit of budworm eggs in 1962. It is also known to have occurred in association with a spectacular increase in parasitization by one of the budworm's less common parasites, Bracon politiventris. This parasite paralyzes 5th and 6th instar larvae and lays its eggs on them, externally. Several may develop on a single larva.

Black Hills beetles take off and fly in search of a new tree to attack as soon as they emerge from an infested pine. During these flights, they are subject to bird predation. Recent studies in Colorado indicate that bird feeding accounted for about 10 percent of the beetle population. The birds include the white-breasted nuthatch, pigmy nuthatch, western wood pewee and a flycatcher. None of them depend on the beetle as a primary food source, and none appear to be attracted into stands solely because of the presence of beetles.

Parasitic insect enemies of the lodgepole needleminer in Yosemite National Park were proportional in composition and numbers to the needleminer in both sprayed and unsprayed stands of lodgepole pine 2 and 4 years after helicopter application of Malathion in oil. The spray, applied at a time coincident with moth emergence and flight, caused minimum damage to maturing parasites within the protective covering of mined needles.

Recent studies indicate that the anthocorid Elatophilus (xenotrocheliella) probably inimica D.&H. feeds only on the red-pine scale, Matsucoccus resinosae B.&G. This anthocorid has two generations a year in Connecticut, closely synchronized with

those of its host, and has five nymphal stages. Adults were reared successfully solely on different stages of the red-pine scale. Both males and females were collected in the field, mated in the laboratory, and eggs were obtained. Eggs were laid singly, 6 to 10 days after mating, with each female producing about 20.

Adults of the clerid, Thanasimus dubius Fab., an important predator of the southern pine beetle, live 2 months and females may lay more than 350 eggs each. A single adult destroyes up to 200 southern pine beetles as they enter or emerge from the bark. Clerid larvae require 4 to 6 weeks to become full grown. When bark beetle density is high, a single clerid larva may destroy 300 to 400 bark beetle larvae. This predator completes its life cycle in 70 to 100 days. Adults emerge after most of the bark beetles have left the trees.

A small Ichneumonid parasite, Tesilochus sp., was reared from bark-scarring Nitidulid larvae, infesting southern oaks. Parasitization ranged up to 9 percent.

b. Insect pathogens. Latent virus infections may have been induced in the armyworm, Pseudaletia unipuncta. Occult virus persisted through at least one generation of progeny of treated insects. It was not determined whether the infection was actually latent, or merely chronic at a level too low to be detected readily; but it was found that progeny with sub-lethal infections were significantly more susceptible to active virus infections than progeny from virus-free ancestors.

Studies of the blood cells of this armyworm, were started to establish the normal pattern of phagocytic response of insect blood cells to foreign particles, including virus inclusion bodies. Plasmatocytes, grouped into microplasmatocytes and macroplasmatocytes, constituted the major portion of this insect's blood. Injection with India ink showed that the microplasmatocytes became phagocytically disguised as "adipohemocytes." Both types of plasmotocytes were found capable of phagocytosis, with the microplasmatocytes being the stronger of the two. Injection of highly purified suspensions of virus capsules did not cause virus diseases or death due to other causes. Only at high dosages were differential hemocyte counts substantially altered when injected and uninjected controls were compared. Differential hemocyte counts of granulosis-infected larvae followed those of controls reasonably closely. Microplasmatocytes increased four days after infection and the prohemocytes increased in the later stages of the diseases. A substantial amount of phagocytosis took place in the blood of nuclear-polyhedrosis diseased caterpillars as long as the disease had not yet affected the blood cells severely.

Twenty-three strains of motile, yellow-pigmented streptococci were isolated from both healthy and diseased gypsy moth larvae. Serologically, they belong to Lancefield's Group D; culturally and biochemically they resemble Streptococcus faecalis. In direct feeding tests, these bacteria were pathogenic to gypsy moth larvae and invaded the hemocoele from the gut.

A previously reported microsporidian pathogen from diseased salt-marsh caterpillars, which have been found pathogenic to the Virginia pine sawfly and the fall webworm, has been identified as a new species of the genus Nosema. This organism is not seriously affected by antibacterial substances present in pitch pine foliage.

Application of sprays containing a native polyhedrosis virus and Bt (Bacillus thuringiensis, Berliner), to aspen foliage at several dosage rates, both alone and in combination, reduced populations of the Great Basin tent caterpillar in the Southwest. Treatments with the virus alone gave high degrees of kill, ranging from 84 to 98 percent. Combination virus-Bt sprays were about equally as effective.

Sprays of Bt alone were less effective; however, a high percentage of the larvae that died after treatment with 3 x 10^8 spores/ml contained Bt.

Encouraging results were obtained from a field test application of a Bacillus thuringiensis spray to control the lodgepole needleminer in California. The spray, in the form of a suspension of 90-T Thuricide, was applied to 15-foot infested trees with a backpack power mistblower when the larvae were hatching. Population reductions in excess of 90 percent were obtained.

A cooperative pilot control test against the gypsy moth was conducted in New York, using an emulsifiable concentrate of Bacillus thuringiensis var. thuringiensis Berliner (Thuricide 90T Flowable). Three large plots were sprayed by airplane with 1 gal. of 90T plus 1 gal. water per acre; three with 1/2 gal. 90T plus 1 gal. water per acre; three with 1/2 gal. 90T plus 1-1/2 gal. water per acre; and three with 1/2 gal. 90T, plus 15 x 10^9 virus polyhedra, plus 1-1/2 gal. water per acre. Larvae were in the second and third instars at the time of spraying. The most effective treatment was with the lighter dosage of 90T alone. However, even it failed to produce satisfactory results.

A cooperative pilot control test was also conducted in Maine against the spruce budworm using Thuricide 90T spray, applied by helicopter. Three plots were treated with 1/2 gal. 90T plus 1-1/2 gal. water; three with 1 gal. 90T plus 1 gal. water; three with 1/2 gal. 90T, plus 3/4 gal. water, plus 3/4 gal. oil; and three with 1 gal. 90T plus 1/2 gal. water, plus 1/2 gal. oil per acre. All treatments provided some degree of control, but none were considered satisfactory.

Aerial application by helicopter of one gallon of Thuricide 90T (Bacillus thuringiensis) plus one gallon of water per acre did not provide satisfactory control of the hemlock looper in Washington. Spray application appeared to be excellent, but significant population reductions occurred in only 3 of 20 treated plots. Larvae killed by the Bacillus were recovered from the 4th to 18th day after spraying. Cool temperatures (mostly below 70°F.) slowed down the feeding rate of the loopers and may have been partly responsible for the low degree of control. Larvae that fed on foliage from the sprayed area at higher temperatures in the laboratory succumbed to the Bacillus.

Spore-crystal-exotoxin preparations were derived from four isolates of crystal-forming bacilli obtained from dead larvae of the gypsy moth collected in an infestation apparently free of Bacillus thuringiensis contamination. In feeding tests, they produced a lethal effect equal to or better than that produced by commercial Bt preparations studied thus far. Biochemical and physiological studies are underway to identify and characterize these "wild" Bt-like organisms.

In a small-scale field test in Connecticut, a spray containing the polyhedral virus, Borrelinavirus reprimens, was applied against the gypsy moth. The spray applied by truck-mounted mistblower to a moderate to heavily infested stand, apparently free of the virus, at the rate of 4 gallons (each gallon contained 1 trillion virus polyhedra) per acre. The first wilted larva was found in the plot 15 days after spraying; and the highest number on the 19th day. No virus-killed larvae were found in either of two adjacent check plots. By the 5th larval instar, an average of 1 living larva could be found in the treated plot per 15-minute count; the average number found in the check plots in the same amount of time was 214. Later, a total of 250 egg masses per acre were counted in the check plots and only 45 per acre in the treated plot.

A slime-producing Proteus has been isolated from diseased gypsy moth larvae collected in eastern New York. This organism may cause a so-called "dessiccation" condition often prevalent in dense gypsy moth populations. When cultured in the laboratory, it produces extra cellular slime on a chemically defined medium. It also appears to have a very high water-binding capacity.

Two different fractions of substances antibiotic to insect pathogens have been separated from pitch pine foliage by ethyl ether and ethyl acetate, and partially purified. Studies with infra-red and UV spectra indicate that they are chemically related to tannins since they are aromatic carboxylic acids with polyhydroxy functional groups. Antibacterial activity was not eliminated by converting the carboxyl group to a methyl ester. The active substances do not appear to be pine oils. They are stable at both high and low temperatures; are highly soluble in water; and are readily dialysiable through a cell membrane with a pore size of 24°A. Their molecular weight is less than 30,000. These substances, which occur in foliage throughout the year, are antibiotic to Bacillus thuringiensis.

An experiment in Massachusetts studied the efficiency of the sterile-male release technique in reducing populations of the gypsy moth. Irradiated males were released at four points in each of several plots containing populations of 45 male and 45 female pupae per acre. Irradiated pupae had been exposed to a Cobalt-60 gamma source with a dosimetry of 8.4×10^5 roentgens/hour. Seven to 10-day-old pupae received 20,000 roentgens. The ratio of irradiated males to nonirridiated males in the various plots were: 11:1, 10:1, 17:1, 36:1, and 30:1. The average percent of eggs hatching in these plots were as follows: At the male dilution of 11:1, 28 percent; at 10:1, 38 percent; at 17:1, 20 percent; at 36:1, 17 percent; at 30:1, 18 percent, and where no irradiated males were released, 72 and 75 percent.

c. New approaches to insect control. A virgin female carpenterworm moth placed in a trap cage during mid-May in Mississippi attracted 316 male moths in 5 days. Nine of 12 marked males released within 150 yards were attracted to the trap and captured. Sixteen of 53 males marked and released 1/4-mile distant were recovered; several others were trapped after release 1/2 mile away; and one from a distance of 3/4-mile. Female moths did not release the attractant continuously. It was most potent from noon until dark. Extracts prepared from the abdomen of virgin females elicited positive responses from males in the laboratory.

Recent studies indicate that the smaller European elm bark beetle, the principal vector of Dutch elm disease in this country, may not be attracted to elm from any appreciable distance. When beetles are exposed to elm twigs, they apparently simply wander around until they encounter one of the twigs. Once they find one, however, they almost always remain on it and feed. Twigs from non-host trees do not elicit a feeding response. So far, efforts to extract and isolate from elm bark the stimulants responsible for the insect's host specificity have been unsuccessful.

Further progress was reported in studies of the differential toxicity of monoterpene vapors to the western pine beetle. This bark beetle appears to be the more adversely affected by resins containing the greater amounts of limonene and Δ3-carene. Oviposition of surviving beetles may be reduced by some monoterpenes and their mixtures. The terpenes limonene and Δ3-carene were far more toxic than a-pinene or B-pinene to the mountain pine beetle. The reaction to various monoterpenes by mountain pine beetles reared from sugar pine and lodgepole pine was parallel. Pitch tubes formed by western pine and mountain pine beetles were used to determine the monoterpene composition of the resin of ponderosa pine.

d. P. L. 480 Projects

(1)-SPAIN

a. Parasites, predators and diseases of the gypsy moth. Several thousand specimens of the parasites of Tricholyga segregata and Brachymeria intermedia were shipped to the U.S.A. for liberation in gypsy moth infested stands. Continuing progress was reported in controlling the gypsy moth by dusting with Bacillus thuringiensis formulations.

(2)-INDIA

a. Survey for natural enemies of the gypsy moth. Many species of Lymantriids were collected and submitted to taxonomists in this country and England for identification. The gypsy moth, Porthetria dispar, was collected in Kashmir. A large number of parasites and predators attacking it were collected, and many were identified.

b. Survey for natural enemies of the balsam woolly aphid on silver fir and spruce in the Himalayas. Progress was reported on biological studies of two promising species of predators: an anthocorid, Tetraphleps sp., and a dipteron, Leucopis spp. Tetraphleps sp. was specific on Adelges and its appearance synchronized with the outbreak of its host.

Two generations per year of Leucopis spp. recorded. Several shipments of eggs and pupae of Tetraphleps, Leucopis and Hemerobius sp. were made to this country during 1963.

(3)-PAKISTAN

a. Investigations on the predators of Adelges (the balsam woolly aphid) on fir. Progress was reported on studies of the biology, seasonal history and feeding habits of the more specific predators of the aphid, and in determining their efficiency in control. Predators receiving special attention were Tetraphleps sp. nr. pilipes, Tetraphleps sp., two species of Chrysopa, and Hemorobius adelgivorus. Seven shipments containing 1785 nymphs and adults of Tetraphleps sp. nr. pilipes made to this country.

b. Natural enemies of insect pests of West Pakistan forests. A large number of parasites and predators of wood borers, sawflies, and insects infesting cones and seeds collected, and many were identified. Few, if any, of these occur in this country.

(4)-POLAND

a. Development of improved strains of parasites of forest insects. Studies on longevity of individuals in pure strains of the parasite Dahlbominus alboannulatus which were collected in different parts of Poland were completed. The most effective strains did not always exhibit the highest biotic activity.

b. Activity of the parasite, Trichogramma embryophagum, when introduced into a forest environment. In the laboratory, this parasite becomes active when rising temperatures reach 12°C., and begins making flight attempts when they reach 17°C. Progress made in mass-rearing of the parasite.

c. Insects noxious to young pine stands. Data collected following extremely cold winter of 1962-63, showed that European pine shoot moth larvae began dying in large numbers when exposed to temperature of -25°C. At -27°C. population was greatly reduced; at -30° it was eliminated. In many areas populations increased again in 1963. A total of 29 different species of parasites of the shoot moth were recorded. Most frequently collected were Ephialtes sagox, Pimpla examinator, Pristomerus orbitalis, Omargus buolianae, Orgilus obscurator, Actia nudibasis and Actia sp.

2. Chemical Control

Many species of forest insect pests cause considerable damage despite efforts to reduce or prevent high populations by means of biological or silvicultural methods. Until such time as these methods are developed or improved, it will be necessary to continue to use insecticides to prevent intolerable losses.

a. Systemics. Early spring application of 10 percent granular phorate (Thimet) around the bases of young pines has given almost complete protection against Nantucket pine tip moth attack in areas where tip moth population pressure was not high. Phorate is highly toxic to wildlife; therefore, it is not being recommended for general use in tip moth control.

Five-year old phorate (Thimet)-treated cottonwoods averaged 49 feet tall and 7 inches d.b.h. Untreated trees of the same age averaged 46 feet tall and 5.6 inches d.b.h. Treatments were made at the time of planting. Similar figures for 4-year old treated trees were 46 feet tall and 6 inches d.b.h., and for untreated ones of the same age 41.5 feet tall and 5 inches d.b.h. Treated trees in both age groups contained one more 4-foot pulpwood bolt per tree than the untreated trees, due to straighter, unbranched trunks.

In recent studies over 3,000 thornless honey locusts were treated in Ohio with the systemic insecticide, Bidrin, in studies on control of the mimosa webworm. A single application by implantation resulted in season-long protection of 92 percent of the trees. The remaining 8 percent were protected by a repeat application.

Treatment of white pines, 7 to 12 inches d.b.h., with the systemic Bidrin provided fair control of the white-pine cone beetle. The material was applied in horizontal cuts into the trunks at rates of 0.25, 0.50 and 1.0 ml. per square inch of basal area. Percentage control increased with increasing dosage. Phytotoxic effects were produced at points of application of all dosages.

b. Conventional materials. Malathion gave effective control of the larch casebearer in Idaho when applied experimentally at dosage rates as low as 1/4 pound per gallon of fuel oil per acre.

Applications of 2 and 3 lbs. of ethylene dibromide emulsified in 4 gallons of water to standing ponderosa pines infested with the roundheaded bark beetle, Dendroctonus convexifrons, gave over 99 percent control of second and third instar larvae in late April; and 95 to 99 percent control of mature larvae, pupae, and callow adults in late July. Applications of 1 lb. EDB in fuel oil killed 100 percent of the brood in both April and July.

The following insecticidal materials were screened for control of the gypsy moth: SD 7438, SD 7694, SD 7697 (Shell Development Co.); MC-A-600 (Mobil Chemical Co.); Ryania 100 (S.B. Penick Co.); and Zectran (Dow Chemical Co.). DDT was used as a standard in all tests. Addition of Zectran and MC-A-600 to media on which test

insects were fed gave higher kill of larvae than DDT at equal concentrations.

The insecticide, dimethoate, also known as Cygon, gave promising but inadequate control of the spruce budworm in Colorado when applied at dosages of 4 ounces and 8 ounces of actual dimethoate in one gallon of water per acre by helicopter. Application against 5th instar larvae gave approximately 85 percent reduction at both dosages. Applications against 3rd instar larvae were less effective.

Recent studies indicate that lindane-diesel oil sprays can be used to control overwintering broods of the western pine beetle in California. Where beetle-infested ponderosa pines were felled and treated with 1.0 and 1.5 percent sprays in November, December, January, and February, better than 90 percent kill of the beetle was recorded the following April.

Oil solutions of lindane, heptachlor, dieldrin, DDT, Guthion, and malathion were screened in California to determine their effectiveness in controlling adults of the Douglas-fir cone midge as they emerged from the duff. Lindane applied at the rate of 1.5 lbs. in 15 gallons of diesel oil per acre was the most effective; Guthion and malathion the least. In a separate study, when lindane was sprayed on the duff on a 10-acre plot in the Six Rivers National Forest, at the rate of 1.5 lbs. in 15 gallons of diesel oil per acre, the midge population was reduced 80 percent. It was later found that the number of cone scales infested was reduced by 40 percent, and the seed yield increased by 38 percent.

Various thin layer chromatographic techniques were investigated for efficiency in defining certain systemic insecticides in white pine. A solvent system of butanol, acetic acid, and acetone was found to carry Bidrin, Zectran, Bayer 39007, and Bayer 29493 sufficiently to allow separation in laboratory extracts of young white pine cones. A reagent schedule of bromine fumes, fluorescein, and silver nitrate made the insecticide spots clearly visible.

It was determined that significant reductions could be made in previously reported lengths of treatment time with vacuum (partial atmospheric) fumigation and still obtain 100 percent control of the European pine shoot moth. Studies were made on 2-0 ponderosa pine seedlings in standard bales, and in two sizes of polyethylene-lined Kraft bags in which infested bud clusters were placed. Completely equipped commercial fumigation chambers were used.

In a cooperative study with New York State Division of Forestry quantities of DDT and lindane in residues remained greater for as long as 165 days after spraying where Aroclor 5460 was included in the spray formulation. In the laboratory, Foxlene (a product derived from pine resin), was superior to Aroclor 5460 in reducing penetration of insecticides into plant substrates.

Treatment of green pine stumps with 1.0 percent BHC emulsion spray was highly effective for 3 months in preventing establishment of black turpentine beetle infestations. A spray consisting of a BHC emulsion plus a wetting agent was 98 percent effective for at least 6 months in protecting pines skinned by logging equipment from attack by this bark beetle.

Preliminary field studies in Florida showed that slash pine cones received fair protection from attack by coneworms (Dioryctria spp.) and excellent protection from the slash pine seedworm (Laspeyresia anaranjada) when drenched with sprays of 0.5-and 1.0 percent water suspensions of Sevin 50-W. Spray applications were made with a hand-operated, 1-gallon compressed-air sprayer on May 2 and May 29.

Studies of spray distributions from a TBM airplane flying at heights of 100 to 150 feet and at 200 feet, showed only a slight and insignificant decrease in the amount of spray recovery from the 200 foot flights.

Studies to determine spray atomizations which can be obtained by a helicopter showed that the flat pattern spray nozzle produced a finer atomization than the hollow-cone nozzle when the spray orifice was directed forward and down into the air stream with a spray output of 0.4 to 0.44 gallons per minute per nozzle. The same atomization was obtained with outputs of 0.6 g.p.m. from the flat spray nozzle and 0.29 g.p.m. from the hollow-cone nozzle. This indicates that flat spray nozzles would be the most efficient on helicopters.

3. Silvicultural Control

It has been demonstrated that damage by some insects can be prevented or reduced by means of various timber management practices such as removing high risk trees and changing stand composition and density. Development of such control practices requires a thorough knowledge of the biology and ecology of the insects involved. Past experience has shown that when silvicultural control can be applied, it is one of the safest, cheapest, and most effective methods of all for preventing or reducing forest insect-caused losses.

a. Barkbeetles. Studies were made of soil conditions in stands attacked by the southern pine beetle at 55 locations in Texas. Rains and Caddo soil series were those most frequently associated with infestations. In virtually all infested spots investigated, soils were imperfectly or poorly drained. While sites were good to excellent, radial growth had slowed perceptibly, especially in high density stands.

b. Defoliators. Recent studies in the Lake States indicate that site index for balsam fir is not related to damage or mortality resulting from spruce budworm defoliation. They also indicate that mortality increases with increased basal area of balsam fir per acre. The flowering condition of fir stands was not found to be related to damage. On the other hand, the abundance of white spruce in balsam fir stands was positively related to the percentage of the fir that was killed.

4. Biology and Ecology

Knowledge of the biology and ecology of insects is prerequisite to their control, be it by direct or indirect methods. No two insects are alike in their life histories, habits, or behavior. No two react alike to the complex of environmental factors affecting them. No two have exactly the same feeding habits or nutritional requirements. Some have a wide range of hosts; others are confined to single hosts. Some are even more restrictive, requiring not only single hosts but those in particular degrees of vigor. Some are widespread in distribution; others much less so. Conditions conducive to outbreaks are recognized for a few species. The causes of outbreaks of others, many of which are extremely destructive, are unknown. Much of the above applies equally to the insect enemies of forest insect pests. Success in forest insect control hinges largely on the status of our knowledge of insect biology and ecology.

a. Barkbeetles. Under laboratory conditions, exposure of the southern pine beetle, Dendroctonus frontalis, for 4 hours to temperatures of 100°, 105° and 110° F. caused 12.5, 97.5 and 100 percent mortality, respectively.

Four techniques have been developed for the mass rearing of two important bark beetle pests of southern pines, Dendroctonus frontalis and Ips calligraphus. The simplest consists of rearing the insects in small infested or fresh bolts which fit snugly in transparent plastic boxes. A second consists of introducing up to 4 pairs of beetles into a sandwich, composed of inner pine bark, between plastic plates; a third of imprisoning a pair of beetles in a gelatin capsule cemented to a fresh pine bolt; and a fourth, of confining 6 to 10 pairs of beetles in a chamber constructed over the end of a short bolt. The latter provides an adequate supply of beetle eggs and larvae for experimental purposes as needed.

Using recently developed techniques, populations of Dendroctonus frontalis and Ips calligraphus have been reared continuously for at least 15 generations. A critical factor affecting success in continuous rearing was found to be bark moisture: it must be held between 50 and 60 percent. So far, there have been no noticeable physiological or morphological changes in the population reared continuously for 15 generations.

An artificial medium comprised of an anti-microbial agent, fresh, macerated inner-bark of Douglas-fir, brewer's yeast, and water has been developed for rearing of the Douglas-fir beetle. Larval growth on the medium is variable, possibly because of the moisture content of the medium which varies and is difficult to control. Diets containing about 60 percent water and 1 to 1.5 percent brewer's yeast appear to be optimal for larval development.

Recent studies indicate that there may be only one generation of the mountain pine beetle per year in the Pacific Northwest. In contrast, Oregon pine ips apparently has two generations per year. It also appears that the latter cannot overwinter successfully in this area in any but the adult stage.

Progress was made in developing methods for sampling mountain pine beetle infestations in lodgepole pine. A 6" by 6" bark sample was just as good as a 6" by 12" sample for measuring attack density, inches of egg gallery and total gallery length per attack. Mortality was greater within than among broods at attack densities of 2 or less per square foot. An increase in attack density resulted in greatly increased mortality among broods.

Recent studies in Idaho indicate that a sizable proportion of Douglas-firs attacked by the Douglas-fir beetle are not killed. This was the finding when 740 trees were examined 14 months after they were attacked by the beetle. At this time, 48 percent of the trees were dead, 29 percent were dying, and 28 percent had live, green foliage. There was no appreciable difference in the age of these trees, but those still alive and green tended to be smaller, slower growing, and shorter than the others. Moreover, they had been less heavily attacked and for shorter distances up the trunks than the dead and dying trees. Further study is needed to aid in understanding these findings.

b. Defoliators. During the period 1954-56 an outbreak of the Douglas-fir tussock moth occurred in white fir stands in California. During the next 5 years, 20 percent of the merchantable trees, or over 11,000 board feet per acre, had died in heavily defoliated stands. Another 1,100 board feet per acre was lost owing to radial growth reductions in partly defoliated trees, 12 percent of which were also top-killed.

In the Pacific Northwest, larval development of the hemlock looper on understory deciduous shrubs, such as vine maple and huckleberry, proved to be a good indicator

of larval development in the hemlock overstory. This means that understory collections can be used to provide needed information for timing control operations. Counts of looper eggs on mossy logs and in breast-high boles on tree trunks were sufficient for outlining areas of looper infestation. The most efficient and reliable method of predicting damage to overstory trees is to fell trees and count the eggs on bole sections removed at midcrown.

Elm spanworm eggs stored at 32°F. hatched when removed from storage before the end of April. Earlier findings that only a small portion of spanworm moths in flight are females were verified, which indicates that moth flights may not be an important factor in long-distance spread of the insect. Young spanworm larvae are carried about by the wind, however, and may be an important factor in local spread.

Heavy defoliation of western larch by the larch casebearer for 7 consecutive years in Idaho has not caused any tree killing as yet. Increment core measurements indicate, however, that these trees have suffered a 55 percent reduction in growth rate during this period.

Studies of the reproductive potential of the black-headed budworm in Alaska indicate that the number of eggs laid per female is directly proportional to pupal size and the length of the egg laying period. Larvae reared on Sitka spruce in the laboratory produced larger pupae than larvae reared on hemlock and resultant female adults laid more eggs. The average number of eggs produced by females reared as larvae in the field was 86. About three-fourths of these were deposited.

Recent studies in Alaska show that third and fourth instar larvae of the black-headed budworm consume or otherwise destroy significantly more hemlock needles than Sitka spruce needles. The reason for this could be simply that hemlock needles are shorter at this time than spruce needles. By the time budworm larvae reach the fifth instar, needles of both species are equal in length and no significant difference in their defoliation is noticeable.

Young ponderosa pines heavily defoliated by the needle-sheath miner in California in 1960 and 1961 suffered a loss in growth increment both during the second year of defoliation, 1961, and during 1962, the year after the last defoliation. In 1963, the defoliated trees showed a marked increase in growth.

The fate of female gypsy moths in the late larval-prepupal age interval appears to be the most important factor in determining population trends or actual population densities under most circumstances. When density at the beginning of a generation is low, however, the survival rate of the small female larvae most strongly influences trend. Variations in the incidence of disease and in the rate of mortality from agents other than disease or parasites largely determines the mortality rate among female large larvae and prepupae when data from all-sized populations are pooled. When data are stratified by population density, however, disease is a critical factor only among dense populations. In sparse populations, other factors are more important.

Recent studies indicate that lipids comprise 6 to 12 percent of the live weight of Virginia pine sawfly larvae. Ten to 20 percent of them were unsaponifiable and 80 percent behaved as fatty acids. Separation of the lipid components shows that 1.5 percent of the total lipids behave as hydrocarbons, 2 percent as sterol esters, 52 percent as triglycerides, 3 percent as sterols, and the remainder as polar materials. Nine fatty acids and 4 sterols were identified. Three sterols were also found in Virginia pine foliage: beta sitosterol, campesterol, and cholesterol

(about 1 percent of the total). The insect converts beta sistosterol into its own major sterol, cholesterol.

c. Seed and cone insects. Approximately two-thirds of red pine cones collected in nine different places in the Lake States in 1962 and 1963 were infested by insects, mostly by the red pine cone beetle and Dioryctria moths. Also, about 12 percent of the white spruce cone crop of 1962, which was still on the ground in 1963, was infested by the spruce seed moth. Greatest incidence of attack by the latter species occurred on cones near the stem.

The periods of significant attack of cones and seeds of ponderosa pine by cone moths of the genus Laspeyresia in the Northwest is from around June 1 to about July 10, with heaviest attack occurring from June 6 to June 20. Attack apparently ceases by July 15.

A recently completed 5-year study of insects affecting seeds and cones of white spruce in interior Alaska showed that they damaged from 3 to 6 percent of the seeds per cone during the first four years and at least 50 percent in the fifth year. Pegohylemia sp. was the most destructive species encountered. Others involved included Laspeyresia youngana (Kft.), Megastigmus piceae Roh., Dasyneura canadensis Felt., D. rachiphaga Tripp, and Phytophaga carpophaga Tripp. Damage was least when there was an abundant seed crop and the number of seeds per cone was high.

In the Central States, acorns of some oaks matured in one season, while those from others required two seasons. Attacks by the curculionids, Conotrachelus naso Lec., C. posticatus Boh., and C. carinifer Casey, were much heavier on acorns that mature in one year than on those maturing in two years.

The cone beetle, Conophthorus ponderosae, destroyed from 10 to 41 percent of ponderosa pine cones in study areas in California. In addition, seed moths, believed to be mainly Laspeyresia miscitata, destroyed up to 32 percent of the seed in cones not destroyed by the cone beetle. Some damage was caused also by Dioryctria auranticella, D. abietella, Eucosma bobana, and cone midges, probably Rubsaamenia sp.

White-pine cone beetle adults hibernate on the forest floor, in cones infested the previous year, in the Northeast. They leave these cones in the spring (usually during the last two weeks of April) and fly to one-year-old cones on the pines. The female usually initiates an infestation, attacking a cone at the junction of cone and petiole, and girdling it within an hour. She then burrows down the axis of the cone, depositing eggs in niches chewed into the gallery wall, at the rate of 1 egg per 7 mm. of gallery. Larvae feed indiscriminately on cone and seed tissue. There are two larval instars. Young adults can be found in the cones by the second week of July. Some beetles emerge from the cones and attack first-year conelets, but most stay within the brood cone until the following spring. Each egg-laying female may attack up to 4 one-year-old cones. Where most of the maturing cones are infested, the beetles attack male and female flowers and vegetative shoots. No developing larvae have been found in these sites.

d. Plantation insects. Preliminary studies indicate that failure of slash pine oleoresin to crystallize may be the most important factor responsible for the apparent resistance of this pine to damage by the Nantucket pine tip moth. Crystal formation appears to be prevented through the formation of an amorphous coat of oleoresin on the outside. Oleoresin of loblolly and shortleaf pine, two species susceptible to tip moth damage, crystallize internally and the outside remains gummy

until crystallization is complete. Permanent damage by the tip moth is caused only by third and fourth instar larvae. In slash pine almost all larvae have died before this time.

Measurements of young pines during the past 5 years throughout the Deep South, indicate that Nantucket pine tip moth infestation has little effect on height growth unless at least 75 percent of the branch tips are infested. Where infestations are heavier than this, many of the tips contain several tip moth larvae and are killed back 6 to 12 inches. This results in stunting growth and causing excessive branching.

Studies of the pine root collar weevil, a pest in pine plantations in the Lake States, show that larger pines are more seriously damaged than smaller ones with the same degree of root collar girdling. Trees are killed when girdling exceeded about 85 percent of the stem circumference.

The European pine sawfly feeds on the old needles of young Scotch pine in the Lake States, causing losses in leader elongation of 14, 23, and 37 percent for groups of trees containing 10, 25, and 50 sawfly colonies each, respectively. Removal of all old needles by hand reduced leader elongation by 63 percent.

Dispersal of the European pine shoot moth, from a focus of local infestation in Seattle, Washington, occurred in all directions. Greatest distance of spread in any direction was 253 feet. The shoot moth larvae left needle bases to attack buds while in the 2nd and 3rd instars and overwintered in the 3rd and 4th larval instars, the same as reported in eastern North America.

The pine weevils, Pissodes strobi and P. approximatus, two morphologically similar but behaviorally and cytologically different species, were hybridized to determine the significance of reproductive incompatibility as a mechanism isolating these weevil populations. In a study of reciprocal crosses, only the hatch of eggs from the cross involving P. approximatus males and P. strobi females was different. Here, approximately only 50 percent of the eggs hatched as compared to 75 to 80 percent in the other crosses.

e. Miscellaneous insects. Studies in the Pacific Northwest continue to show subalpine fir to be more susceptible than grand fir to the balsam woolly aphid. For example, some 55 percent of 270 infested and tagged subalpine firs died during the past 5 years on a study plot in western Oregon, while only 2 percent of 242 grand firs on another plot in the same general area died during the past 4 years. The largest trees of both species were the first to be attacked and killed.

At least 50 percent of the new needles on grand fir are lost after 6 years of infestation by aphids. In trees infested 10 years, 85 percent of the new needles and 10 percent of the old ones are gone. After 14 years infestation, loss of new and old needles amounts to 95 and 80 percent, respectively. Reductions of height and diameter growth are of similar proportions.

Chromatographic analysis of honeydew secreted by the yellow-tulip scale, a pest of yellow poplar, shows that it contains maltose, glucose, fructose, raffinose and glacturonic acid. There is no evidence of sucrose, the most concentrated of the sugars in the sap. Maltose is not found in the sap. Honeydew also contains the amino acids glutamine, serine, aspartic acid, glutamic acid, alanine, tyrosine, valine, isoleucine, lysine, and asparagine. The most concentrated of these acids is lysine, with alamine running second. Glutamine is reported to be the principal

amino acid in yellow poplar.

Lumber from samples of logs of six southern oaks showed an average value loss of $20.00 per thousand board feet from degrade due to insect-caused defects. This indicates a probable value loss of $60 million from insects in the 3 billion board feet of oaks cut annually in southern forests.

f. P. L. 480 Projects

(1)-SPAIN

a. Biology and control of insect pests of poplar. Adults of the borers, Paranthrene tabaniformis and Cryptorrhynchus lapathii, emerged from May 4 to September 2 and June 20 to September 3, respectively, in the Madrid area. P. tabaniformis oviposited throughout its period of emergence; C. lapathii from July 12 to September 19. Saperda carcharis adults emerged from August 20 to September 20. Some differences in susceptibility among various clones to P. tabaniformis and to C. lapathii were recorded; none to S. carcharis.

(2)-TAIWAN

a. Biological study of the more important insect pests attacking genus Pinus introduced from the U.S.A. General surveys in Taiwan show that nine species of American pines have been introduced and planted on the island since 1930; namely, slash, loblolly, Monterey, short leaf, long leaf, benguet, eastern white, jack, and pitch. Slash grows best and is most widely distributed. From July to November 1963, at least 185 different species of insects were collected on these pines.

(3)-PAKISTAN

a. Survey of insect fauna of West Pakistan forests. This project has been underway only one year and progress has been limited to date.

(4)-POLAND

a. Growth, development, and disease and insect susceptibility of some species of trees from the U.S.A. planted in the Baltic, Great Valleys and Middle Mountains regions of Poland. Western red cedar, eastern hemlock, and Douglas-fir planted in the open suffered damage by the weevil, Hylobius abietis L.

(5)-FINLAND

a. Orienting stimuli guiding insect pests to suitable forest trees. Continuing progress was reported in isolating the substances in the bark of red pine that are attractive to the bark beetle, Blastophagus piniperda. Phloem extracts were fractionated and sub-fractionated with the aid of a gas chromatograph. The fraction showing the clearest attractant influence has an agreeable odor resembling the smell of sawdust; is a slightly acid oil with a positive phenol reaction; and contains infrared spectrum absorption bands, possibly due to the presence of aromatic compounds.

(6)-URUGUAY

a. Species adaptability and insect and disease susceptibility of North American conifers planted in Uruguay. Reports severe attack by Evetria buoliana on 2-7 year old plantations of Pinus radiata.

(7)-COLOMBIA

a. Species adaptability and insect and disease susceptibility of some North American tree species planted in Colombia. Pine plantations at Bogota infested with two species of chrysomelids, Epitrix paroula and E. cucumeris. Good control was reported following application of "Insectosan."

5. Wood Products Insects

Insects that damage or destroy wood products cause heavy losses in this country each year. In spite of the fact that considerable progress has been made in past research in methods to prevent or control populations of these insects, losses are still severe.

a. Powder-post beetles. Ten-second green dips of starch-rich, ash boards in 0.5 percent solutions of aldrin, dieldrin, and heptachlor, and in a 2.0 percent solution of chlordane, followed by kiln drying, resulted in complete protection from Lyctus powder-post beetles for as long as 4 months after drying.

Sweetgum logs stored under a continuous coarse spray of water during the summer remained almost completely free of insect attack for 3 to 6 months. Application of water as a fine mist in earlier studies resulted in no appreciable control. The coarse spray sprinkling treatment also provided 100 percent protection against unidentified Cerambycid and Buprestid beetles which attacked untreated logs fairly heavily.

b. Termites. Studies of subterranean termintes in Wisconsin indicate that the rate of termite feeding is increased when wood is decayed and that termite survival is improved by a diet of decayed wood. Survival improvement began with incipient decay but did not change thereafter by greatly increased decay.

Subterranean termites heavily damaged samples of laminated oak flooring and Douglas-fir plywood in which dieldrin had been added to the glue by the manufacturers.

In field studies involving chemically treated soil exposed to the elements, 100 percent protection of wood from subterranean termites has been obtained from 1.0 percent chlordane for 15 years; from 0.5 percent aldrin and dieldrin for 14 years; and from 0.5 percent heptachlor for 11 years. Tests are still in progress and the maximum years of protection from these chemicals eventually will be known. Application of granular formulations of these chemicals to the surface of the soil has provided 100 percent protection for 5-1/2 years, the length of time the tests have been underway.

6. Survey Techniques

Studies are conducted to provide survey methods for those insect species where none now exist and to improve upon methods presently in use.

a. Aerial surveys. Recent studies indicate that some of the newer photographic emulsions offer certain advantages over the emulsion currently used in evaluating insect-caused damage to forests by aerial photography. However, none of these new films rendered colors equal to that produced by the film now in use. Color is, of course, the most important film quality in evaluating insect-caused damage by aerial photography.

b. Ground surveys. Tree mortality in spruce-fir stands heavily defoliated by the spruce budworm in Minnesota during the past 6 years has reduced the number of merchantable living trees by 29 percent and the volume by 30 percent.

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C. FOREST DISEASES

Problem

Diseases occur in all parts of the country irrespective of land ownership, on all forest tree species, hardwoods and conifers alike, on trees of all ages from the seeds themselves to overmature forest veterans, and affect all parts of the tree from the root tip to the terminal bud and from the outer bark to the central pith. Other forest plants important to forage, recreational, and watershed values are equally subject to attack. These diseases are caused by a wide range of biotic agents such as flowering plants, fungi, bacteria, nematodes, and viruses and an equally diverse assortment of abiotic factors such as temperature and moisture extremes, nutritional excesses or deficiencies, and noxious substances in the atmosphere. Working singly or in combination these factors may induce disease causing death, loss of growth, deformity, lowered quality, or destruction of wood already formed in forest trees. In total, they cause as much loss in our forests as all other destructive agents combined, including fire, insects, and animals. In terms of volume, this growth impact amounts annually to 5 billion cubic feet of growing stock, including 20 billion board feet of sawtimber -- a loss almost equal to the annual cut of timber in the United States. In addition, many of these or other agents continue their destruction of wood products extracted from the forest to cause additional losses estimated at $300,000,000 per year.

USDA and Cooperative Programs

The Department has a continuing long-term program of basic and applied research directed toward the solution of forest tree disease problems and the development of means for their control. The program is a national responsibility of the Forest Service and is conducted at 9 of the 10 Forest Experiment Stations, the Forest Disease Laboratory attached to the Washington Office, and the Forest Products Laboratory. Each of the Stations conducts research on a variety of diseases of especial importance in their geographic area of responsibility and may also have leadership for research on diseases of broader regional impact. The Lake States Station, for example, has primary responsibility for research on hypoxylon canker of aspen, the Central States Station for oak wilt, the Pacific Northwest for Poria root rot of Douglas-fir, the Intermountain for breeding western white pine for resistance to white pine blister rust, and the Southeastern Station for research on air pollution as a cause of forest tree diseases.

The Forest Service now devotes 72 professional man-years of effort to research in this area and has general supervision over another 26 man-years of foreign professional effort devoted to twelve PL-480 projects abroad. Over one-half of the Forest Service scientists are plant or forest pathologists but to provide all of the talents required, especially for more basic research aspects, biochemists, ecologists, serologists, meteorologists, nematologists, physiologists, microbiologists, and soils scientists are also employed.

This research program is carried out in cooperation with other Federal, State, and local public agencies. Oregon State University, for example, provides mensurational assistance on the study of dwarfmistletoe growth impact on ponderosa pine; the Georgia Forest Research Council provides financial aid and the Georgia Forestry Commission labor, land, and equipment for research on fusiform rust and nursery diseases; Montana State University is working out the life history of Elytroderma

deformans; the Universities of Missouri, West Virginia, and Pennsylvania State coordinate their researches on oak wilt with the Federal program; and TVA and the Universities of California and North Carolina cooperate on the study of air pollutants.

Under Public Law 85-934, research grants were made for the first time in 1964, with Yale University to work on the biochemistry of the wood decay process, and with Duke University to work on the aerobiology of the fungi of Piedmont forests.

Under Public Law 480 authority and funds, research programs supplementing and complementing domestic ones are under way in Finland, Italy, Poland, Spain, India, Taiwan, Brazil, Colombia, and Uruguay; some of these projects are designed to disclose native pathogens of special potential threat to North American forest tree species.

Industrial forestry organizations are also active in forest disease research and cooperate with the Forest Service program by freely exchanging research results, making their lands and timber available for study, providing technical consultation, and furnishing labor. Several chemical companies donate their products for experimentation; the Pabst and Upjohn Companies are especially active in this field. The Department of Defense supports substantially the research on the decay of wood in use as do several other major users of wood products and manufacturers of wood preservatives. Annual outside expenditures are difficult accurately to determine but are estimated to be equivalent to one-half the manpower devoted to this project by the Forest Service.

Program of State Experiment Stations

Leadership in forest disease research is providing new knowledge on the major disease problems, which involve an extensive array of bacteria, fungi, nematodes and viruses. Several investigators are concerned with the specialized fungi and bacteria which are variously parasitic and beneficial, i.e. the mycorrhizal organisms. Research is in progress on the mechanism of the mycorrhizal process, both in the well known endotrophic forms as well as in the ecotrophic types. The relation of mycorrhizal activity to root and other diseases of trees is also being investigated.

A number of research projects are designed to learn more of the specialized and destructive vascular diseases such as those of maple, elm, and oak. These studies are coordinated through two Regional Research Projects, in which both the Forest Service and the Agricultural Research Service also participate. Several scientists are concerned with the role of nematodes in forest tree diseases and recent findings have shown that a number of nema species have a pronounced effect on stand establishment. Their impact on growth of trees is not fully understood, either as direct causal agents, as vectors, or as components of a microbial interaction resulting in disease. The role of other soil microorganisms in the control of destructive pathogens, the isolation of resistant germplasm, and the use of specific chemicals for control, are being investigated.

Several scientists are involved in research designed to provide new knowledge which will eventually be used to gain effective control of the destructive rusts and canker diseases of trees. A few research projects involve studies on the naturally occurring bacteria and fungi which have pronounced antibiotic activity with respect to forest tree pathogens. Interest in virus diseases of forest trees, their spread, mode of action, and possibilities for control are also being investigated. Some pathologists are also concerned with research designed to learn more of the biochemical specifics of the disease process in trees, and through these studies are

making substantial contributions to scientific knowledge. These are a few of the areas of abnormal physiology, i.e. pathology, which are under investigation at the State Colleges and Universities.

A total of 21.9 professional man-years is being devoted to forest disease research at the state agricultural experiment stations.

Progress---USDA and Cooperative Programs

1. Seed and Seedling Diseases

a. Causal organisms. The pathogenicity of Macrophomina phaseoli to Pinus lambertiana in constant and fluctuating temperature regimes was demonstrated in California studies. Increasing mean temperatures and increasing amplitudes of fluctuations resulted in an increased rate of mortality in the temperature regimes tested. Fluctuations in temperature also significantly affected the growth rate of the pathogen.

Charcoal root disease caused by Macrophomina phaseoli, was still very active in unfumigated land in California even after 3 years of fallow. Planting of land fumigated 2 and 3 years ago demonstrated that weeds were as much a problem as in unfumigated land, that there was no growth response or increase in seedling size as occurs when the soil is fumigated just prior to planting, and that the reinvasion of the soil by plant pathogenic fungi was occurring as evidenced by early season losses to Phythium spp. and Rhizoctonia solani.

Abies fraseri is a new host for Phytophthora cinnamomi and showed a high degree of susceptibility in a Southeastern nursery where conditions were conducive to disease development. P. cinnamomi was readily isolated from diseased seedlings on cornmeal agar medium containing pimaricin, polymyxin, and penicillin G, or pentachloronitrobenzene (PCNB). Dexon (p-dimethylaminobenzenediazo sodium sulfonate) applied twice at rates of 80 and 120 pounds per acre reduced losses but did not provide a practical control in nursery beds.

Cylindrocladium scoparium, a fungus which causes root rot at other Lake States nurseries, was isolated from the soil at the Chittenden Nursery using the alfalfa technique. It was not recovered directly from seedlings. This fungus may have caused the damage to white pine grown at this nursery in previous years.

Assays of the rhizosphere of sugar pine outplanted in California indicate that there is a gradual shift of microflora from one characteristic of a nursery seedling to one characteristic of a natural seedling. Fusarium oxysporum which is extremely abundant in the rhizosphere of nursery seedlings appears to be replaced over a 1- to 2-year period by Cylindrocarpon sp.

The fungus, Coniothyrium sp., was frequently isolated from yellow birch seeds injured by the weevil, Apion walshii. The fungus was also isolated frequently from chlorotic seedlings. These results help to explain why many seeds do not germinate and why many birch seedlings die at an early age in the Northeast.

b. Nursery soils and chemical controls. Application of organic materials to Bend (Oregon)Nursery soil was earlier shown effectively to control Fusarium root rot of ponderosa pine seedlings. Best results in current tests were obtained with ponderosa pine litter plus fermented layer at a rate of 10 tons per acre. All treatments significantly increased the microbial population, particularly species of Trichoderma and Streptomyces.

The wide carbon-nitrogen ratio of the applied materials, especially pine bark and pine sawdust, caused some initial inhibition of seedling growth. All treatments, except pine litter plus fermented layer at 10 tons per acre, appeared also to reduce mycorrhizal formation.

A summary of laboratory, greenhouse, and nursery seedbed studies of the cause and control of Fusarium root rot at the Bend Nursery shows that heavy summer watering and the addition of a sawdust and mineral fertilizer in the fall following rye as a rotational crop are effective for control of root rot.

Response of ponderosa pine to soil treatment with sulfuric acid and methyl bromide alone and in combination was observed in a study in Bessey Nursery, Halsey, Nebraska. Emergence, survival, weight (green and oven dry), height and diameter of seedlings were higher in plots treated with methyl bromide, than in plots not treated or in plots treated only with sulfuric acid.

Outplantings of 1-0 sugar pine grown in fumigated and nonfumigated California nursery beds were made to compare vigor and survival of stock. Survival of seedlings from fumigated beds was 82 percent while those from nonfumigated was 47 percent.

c. Susceptibility of American trees to foreign pathogens. About 40 pathogens have been isolated from 142 samples of larch, pine, and oak seed and their potential importance and methods of control are under study in Poland. No serious disease losses nor new pathogens have yet appeared on the ten species from 24 North American provenances outplanted at 8 locations in Poland. Twelve genera of pathogens, all known in the USA, have been isolated from pine seed in Taiwan. The most effective surface sterilant tested was mercuric chloride. In Taiwan nurseries, four genera of common damping-off pathogens have been isolated from 5 different tree species. A seedling needle blight of pine was found that may be potentially important in the USA. Nurseries and outplantings have been established but susceptibility results are not yet available from Brazil, Columbia, or Uruguay. (PL-480).

2. Root Diseases

a. Fomes annosus root rot. Of the 8 large-scale stump treatment plots established throughout the Southeast, only 2 had enough Fomes annosus infection in the check to evaluate the relative effectiveness. In the two plots where the treatments could be evaluated, both chemicals tested, 4 percent ammonium fluoride solution and creosote were equally successful in preventing stump colonization by F. annosus. Two months following thinning, less than 5 percent of the treated stumps were infected. Stumps and roots in one of the plots were again checked after 10 months, and F. annosus was present in approximately the same percentage of the fluoride-treated stumps, but infection in the creosote treatment had increased to 41 percent. This emphasizes the importance of long-term evaluation of stump treatments. Stumps treated with ammonium fluoride died within 2 to 4 months, while most stumps treated with creosote, and in one test with borate, remained alive for 6 to 12 months following thinning.

A number of chemicals were tested in a shortleaf pine plantation in southern Missouri to determine their effectiveness in preventing colonization of stumps of freshly-cut trees by Fomes annosus. Materials tested were urea, ammate, ammonium fluoride, Borateem, borax, creosote, and penta-chlorophenol. Although all the chemical treatments considerably reduced colonization by the fungus when compared

with the controls, urea, ammate, ammonium fluoride, and the borate compounds were more effective than creosote or pentachlorophenol.

It is generally accepted that original infection of coniferous stands by Fomes annosus occurs mainly through freshly cut stump surfaces with subsequent spread to residual trees through root contact. The occurrence of root rot centers in unthinned stands and death of residual trees in thinned stands, in shorter periods than can be explained on the basis of the observed rates of growth of the fungus in roots of stumps and residual trees, indicate that Fomes annosus may infect roots directly. To further substantiate this, roots were severed on healthy slash pine in unthinned plantations at two locations in South Carolina, at approximately monthly intervals from November to May. The cut end of the roots was coated with grafting wax and quickly recovered with soil. These roots were removed 4 to 6 months after severing and, along with a similar number of unsevered roots from the same areas, were examined for the presence of Fomes annosus. The fungus was isolated from 7 percent of 604 severed roots sampled. In 60 percent of the infected roots, Fomes annosus had entered through the cut end. In the remaining infected roots, entrance by Fomes annosus had occurred at some distance from the severed end on a previously undisturbed portion of the root. F. annosus was recovered from 1 percent of the non-severed roots. These studies indicated that F. annosus can infect directly through roots, presumably by spores that wash down through the soil. This infection pathway must be considered when formulating control measures.

Freshly cut stumps of shortleaf pine in the Southeast were inoculated with several concentrations of conidia and basidiospores of Fomes annosus. Three months later F. annosus had colonized 37 percent of the volume of stumps inoculated with the highest basidiospore inoculum level, 1400 viable spores per ml., while only 14 percent of the stumps was colonized with the highest conidial inoculation level, 86,000 spores per ml. The next highest concentration of basidiospores, 140 per ml., gave the second greatest amount of colonization. The lowest basidiospore concentration, 14 per ml., and the two highest conidial concentrations, 86,000 and 8,600 spores per ml., yielded colonization levels that were not significantly different from the 9-percent colonization of the non-inoculated stumps, which were naturally infected. The lowest conidial level, 860 per ml., produced a colonization level significantly below that of the checks. This study indicates that conidia of F. annosus, even if they occur in large numbers in nature, may not be an effective means of reproduction.

Stumps of pitch, shortleaf, and Virginia pines were inoculated with spore suspensions of Fomes annosus. Three months later the percent colonization for pitch, shortleaf, and Virginia pine stumps was 31, 13, and 7 percent, while the depth of penetration was 3.7, 3.7, and 1.1 inches respectively. This study indicates that Virginia pine is more resistant to F. annosus than pitch or shortleaf.

Fomes annosus has continued to spread in 3 of 5 study plots established in the Southeast in 1959 in thinned slash pine plantations. These plots, with 12, 5, and 25 percent of the initial stand infected or dead in 1959, now have 31, 46, and 46 percent respectively of the trees infected or dead. Another plot, initially with 35-percent infection, now has 47 percent. For the first time, however, no change occurred in this plot since the last examination. No change has occurred in the remaining plot since it was established in 1959.

Antiserum has been produced to a local isolate of F. annosus from loblolly pine. Cross-reaction studies with other species of Fomes from the Southeast and other fungi, which produce an Oedocephalum type imperfect stage, show the presence of

some common antigens, but also some that are distinctly different from those produced by F. annosus.

Approximately 70 separate Fomes annosus and Armillaria mellea infection centers were found on the Boggs Mt. State Forest in the Coast Range of California. Nearly all F. annosus infection centers were associated with stumps left from a 1948-52 logging operation. Long-term infection and spread plots are now being established at several of the centers. Scattered killing of manzanita (Arctostaphylos spp.) by F. annosus was also found on Boggs Mt. State Forest. This is the first report in California of extensive killing of a brush species by this pathogen. The manzanita isolate of the fungus shows the same type of genetic variation as Sierra conifer isolates.

New techniques were developed in Poland for the study of soil microflora in forest stands heavily damaged and free of damage by Fomes annosus and Armillaria mellea. One soil fungus is abundant in annosus-free stands and uncommon in damaged stands. Measures to stimulate this fungus are under study. (PL-480)

b. Other root pathogens. Phytophthora cinnamomi caused the failure of an experimental planting of 100 Port Orford cedars near Bogalusa, La. Initial survival was satisfactory but after the first winter the trees started to yellow and die. At age 5 only 10 trees were alive. Lesions occurred in the roots and stems of decline trees and P. cinnamomi was isolated from them, demonstrating the potential danger from this fungus to susceptible tree species in the South. Nearby plantings of Arizona cypress were not affected.

c. Soil Microbiology. Study of the influence of interplanted and pure stands of red alder on microbial activity and carbon nitrogen transformation in soils of the Douglas-fir region, being conducted cooperatively with Oregon State University, has shown: (a) the F- and A-horizons to be more acid under alder than under Douglas-fir, (b) both total nitrogen and nitrate nitrogen to be higher in alder and mixed plots than in conifer plots, (c) bacteria to be more abundant in soil under pure Douglas-fir than in soil bearing mixed and pure alder stands, (Streptomyces spp. were least numerous in conifer soil) and (d) rain falling through the canopy and flowing down stems contributes more nitrogen to the soil in the alder plot than in the mixed stand, and least in the conifer plot.

d. Mycorrhizae. Rhizospheres of three morphologically distinct mycorrhizae, a white, grey, and yellow form, and of adjacent suberized roots from a single Douglas-fir were examined and compared with nonrhizosphere soil at the Corvallis, Oregon laboratory. Each microhabitat was found to contain a different population of microflora. Rhizosphere differences between the three mycorrhizae were attributed to associated fungal symbionts. This influence of the mycorrhizal fungus upon the rhizosphere may affect attack of the root by parasitic fungi. Some symbionts may attract a more effective biological barrier than others.

The hypothesis that mycorrhizae, in addition to improving nutrient absorption, benefit tree growth by protecting delicate, unsuberized roots from attack by soil pathogens was examined and pertinent literature reviewed. This suggested that the mycorrhizal fungus may protect the root by (a) utilizing surplus carbohydrates and thus reducing attractiveness of the root to pathogens, (b) serving as a physical barrier to infection, (c) secretion of antibiotics, and (d) attracting, together with the root, protective rhizosphere organisms.

Isolations were made from 116 of 213 sporophores collected as suspected mycorrhizal formers in the marginal timber stands of the Southwest. Thirty-five cultures were obtained from these isolations. The isolations were of two types, viz. spore casts and tissue plantings. Of 229 tissue plantings, 20 percent produced non-contaminants. Boletus granulatus, the most common and widely-occurring species of this genus in New Mexico, was cultured successfully from spores and tissue. Cultures were obtained from 4 other species of Boletus, but their identity has not yet been confirmed. Isolations from 4,169 mycorrhizal root tips, using several techniques, produced 1,914 cultures other than common contaminants. The first of a series of mycorrhizal synthesis trials indicates that at least 2 fungi may form mycorrhizae with ponderosa pine, but none of the fungi tested formed mycorrhizae with pinyon or juniper.

The effects of constant temperatures ranging from 35°F. to 95°F. over varying periods up to 48 days on the growth of seven mycorrhizal Hymenomycetes were measured at the Laurel Forest Disease Laboratory by (a) diameter of colonies on agar medium, (b) dry weight of mycelial pads harvested from liquid media, and (c) by pH of the broth in which the mycelium was grown. Each species used in this basic study of fungus physiology displayed individual characteristics of growth and respiration at different temperatures. It appears that pH can be used as an indication of metabolism, growth, and senescence of fungi grown in liquid media.

3. Stem Diseases

a. Native rusts of conifers. Yellow witches'-brooms caused by rust fungi are associated with several kinds of damage to spruce and true fir. In sample plots in the Rocky Mountains, spruce broom rust caused mortality and declines of more than 20 percent in diameter and height growth rates in infected trees. Fir broom rust appeared to have little effect on growth rates, perhaps because sampled infections were young.

Previous cultures of limb rust fungi were confirmed: Peridermium filamentosum from the Rocky Mountains easily infected Castilleja, except that inoculum from southern Utah caused little infection; P. stalactiforme on Jeffrey pine (Washoe Peridermium) readily infected Castilleja; P. sp. on Jeffrey pine (Inyo Peridermium) did not infect Castilleja.

Study of tissue sections shows that growth of limb rust fungi differs from growth of other plant rusts: (1) longitudinal spread is mainly by hyphal growth within host tracheids; (2) hyphae grow radially in mature xylem, deep in host sapwood; (3) in larger stems mycelium avoids, rather than concentrates in, bark and outer xylem rings; and (4) mycelia become much larger than any previously described for rust fungi.

Comandra rust infection of lodgepole pine has been scarce in Regions 1 and 4 during the last 10 to 15 years. Earlier infections are causing damage in local areas, especially in stands adjacent to rangelands.

The Inyo Peridermium is morphologically distinct from P. filamentosum. Its pycnia were found for the first time.

Western gall rust has been identified on jack pines in several Lake States areas.

b. White pine blister rust. Breeding western white pines resistant to blister rust offers one promising method of combatting the disease in a region where control is complicated by favorable conditions for rust damage to a susceptible species.

Considerable progress has been made at the Moscow, Idaho laboratory toward the goal of 100 acres of F_2 seed orchards by 1974. Three hundred and eighty-five canker-free candidate trees have been located in heavily infected natural stands, and 320 of these are already test-crossed. Thirty out of 111 candidate trees have been reselected for general combining ability for rust resistance. These are being remated within elevational zones, and the F_1 offspring of these special crosses will provide scionwood for grafting work commencing in 1970.

Reselection of test-crossed parents for general combining ability for resistance may be possible when the F_1 test-cross progenies are only 3 years old. For instance, among 60 new canker-free selections test-crossed in 1959 (with F_1 seed sown in the fall of 1960, and with 1-0 F_1 seedlings inoculated in the fall of 1961), 14 were selected for general combining ability on the basis of apparent resistance of the 2-0 seedlings in the fall of 1962. By the fall of 1963 (2 years after initial inoculation, at 3-0 age), only six of the 1962 selections were dropped, and six other parents substituted.

The more than 1,250, 9- to 12-year-old F_1 seedlings in the Moscow arboretum (all survivors of intense artificial inoculation) produced almost 3,000 female strobili in 1963. Trees remain precociously female, only 7 of the 1,250 producing male strobili. Thus, while F_2 breeding is limited, it is beginning. With production of more pollen, the question of gain in resistance in the second generation will soon be answered.

The testing and selection processes for blister rust resistance in seedlings could be shortened considerably if resistance could be detected by chemical means, quickly and conclusively. A study to define the comparative biochemistry and physiology of western white pines resistant and susceptible to infection by the blister rust fungus has been started at the Moscow Laboratory. So far, analytical methods for use in a wide variety of western white pine tissue analyses have been worked out, and many of the biochemical constituents of foliage and bark are now known. At least one phenolic compound is believed to be associated with resistance.

Tuberculina maxima on white pine blister rust cankers now occurs throughout the Inland Empire on western white pine and appears to be a considerable factor in suppressing the rust. A study to investigate its significance is planned.

In eastern Upper Michigan land-to-lake breezes and their higher countercurrents have been implicated as the major controllers of blister rust distribution on white pines in this area of frequent periods of weather favorable to rust spread. Air-weight balloons have been used to help trace their air currents.

Results of studies in the Lake States show that early and frequent pruning reduced the percentage of fatally infected trees from 59 percent to 19 percent in a plantation located in a climate favorable to blister rust infection.

Field tests over the past 5 years in California show that direct spray treatment of white pine blister rust may yield a useful degree of control. For direct treatment of rust cankers in sugar pine 1 to 2 1/2 percent orthophenylphenol in stove oil now appears to be one of the safest, cheapest, and most effective of the fungicides so far tested, including the antibiotics cycloheximide and phytoactin.

Preliminary results indicate that Phytoactin L-341 and Acti-dione BR (each at 200 p.p.m. in a fuel oil carrier) are not effective in controlling white pine blister rust on sugar pine in northern California and southwestern Oregon when used as a basal stem spray. Cycloheximide methylhydrazone as an aqueous root dip at 15, 30, and 45 p.p.m., or as an aqueous soil drench at 100, 150, or 200 p.p.m. appears to provide some measure of immunization against white pine blister rust for sugar pine planting stock at the Wind River (Wash.) Nursery.

c. Fusiform rust. One hundred cc of aeciospores were collected from one medium-sized fusiform rust gall in the South. Such measurements suggest that fantastic numbers of aeciospores are released per acre in heavily-infected stands. The rust mycelium in oak leaves is walled off by dark host cells so that only one or at most two clumps of telia are produced per infection. Thus the number of telia is directly proportional to the number of infections per leaf. In nature, uredia (the repeating stage) are not consistently produced to multiply oak infections. These observations strongly suggest that sanitation cuts to remove infected pines will have an important role in fusiform rust control.

A colorless variant, possibly a mutant, was found as a streak on an otherwise normal fusiform rust gall at Saucier, Mississippi. These colorless aeciospores had a high germination rate and, in greenhouse inoculations, produced abundant colorless uredia on oak leaves. This is the first observed varient of fusiform rust and will be intensively studied because of its possible bearing on the program for breeding rust-resistant pines.

In germination studies at the Gulfport, Mississippi laboratory, the majority of Cronartium fusiforme sporidia formed secondary or sometimes tertiary or quaternary sporidia. Typical germ tubes were observed from all. Only primary sporidia were abjected; the others remained attached in chains with protoplasm only in the last-formed stage. The formation of secondary, tertiary, and quarternary sporidia may increase the life of a sporidium in nature by enabling it to survive periods unfavorable for normal germination.

At the Macon, Georgia, laboratory secondary sporidia of Cronartium fusiforme have been found to be pathogenic on slash and loblolly pine seedlings in artificial inoculation studies.

A technique has been developed at this same laboratory for the preservation of Cronartium fusiforme aeciospores. Spores may be kept in a viable condition for as long as 12 months by drying, vacuum storage, and rehydration.

Fusiform rust infection patterns on oak leaves have been determined. Susceptibility and type of fructification have been found to be determined by leaf age in artificial inoculations.

d. Canker diseases. Data from 1,293 plot measurements show that hypoxylon canker is a very damaging forest disease in northern Michigan, Wisconsin and Minnesota. Its presence is positively correlated with tree age, geographic location, and year, but not with site index. Substantial but inconclusive evidence indicates greater infection on open-grown trees in thinned stands.

The fungus, Cryptostroma corticale, reported to be the cause of the sooty bark disease of sycamore maple (Acer pseudoplatanus) in Europe, has been observed on sugar maple logs in several wood yards, and once on a windthrown sugar maple in the field during the past year. So far, there is no evidence that it is acting as

a plant pathogen in the Lake States, but it is causing considerable problems as a human allergen in mill workers who inhale considerable quantities of the spores during sawing or debarking operations. Knowledge of its development as a saprophyte following cutting and storage of maple logs and bolts is needed in order to formulate storage practices which will eliminate or reduce sporulation.

Portions of the lower trunk of occasional sugar maples in the Lake States are sooty black in contrast to normal grey. Practically all such trees examined have been heavily and repeatedly attacked by sapsuckers. Investigations have shown that sapsucker attacks on sugar maple are concentrated almost exclusively on these black-barked trees and that the black bark can serve as a useful external indicator of internal bird peck defect in that species. The blackened appearance of the bark is due to the saprophytic growth of a fungus complex on the bark surface following release of large quantities of sap from sapsucker wounding in early spring. The fungi involved are similar to those causing "sooty mold" on the foliage and twigs of many plants following aphid and scale attacks.

New isolations of the same fungus from Minnesota Phomopsis cankers on white pine as was obtained from Michigan cankers may indicate a widespread, fairly virulent canker disease. Pathogenicity of the fungus has not been demonstrated.

A new species of Ceratocystis was isolated from aspen black cankers in Colorado.

Artificial inoculations of a 5-year-old American chestnut grafts on Asiatic chestnut rootstocks demonstrated that if a blight-resistance substance is imparted to the graft by the rootstock, it is not in sufficient quantity to induce blight immunity.

The incidence of pitch canker on south Florida slash pine increased rapidly over a 5-year observation period. Removal of all diseased trees in specific plots did not reduce the rate of infection in the residual trees. The disease causes either mortality or malformation, and pitch canker trees should be discriminated against during thinning.

A Nectria canker of mahogony, unknown elsewhere, has been found and described in a study in Taiwan. Precautions to prevent its spread must be taken. (PL-480)

e. Dwarfmistletoes. Further consideration of some of the apparently conflicting results of dwarfmistletoe researchers in the Pacific Northwest suggests that effectiveness of sanitation-thinning in controlling the disease may depend more on the thinning than on the sanitation, i.e., that trees with adequate growing space, at least on fair to good sites, may be able to keep ahead of the upward progress of the parasite long enough to produce a fairly good yield of commercial material, even though the sanitation was not very thorough. Evidence is scanty and circumstantial, but the importance of this theory in determining practicability of control is so great that dwarfmistletoe research efforts must obviously be devoted largely to it during the next several years.

The distribution and frequency of infection by dwarfmistletoes in a portion of western Montana was determined by a survey of 2,090 sample plots in the Clark Fork Unit, which includes some 3,400,000 acres of commercial timberland. Dwarfmistletoes were present in 23 percent of the plots. Ten percent of the 22,863 trees on all plots were infected, but 38 percent of the trees on the 474 infected plots had dwarfmistletoes.

Data on dwarfmistletoe in young lodgepole pine regeneration in the vicinity of infected residual stands were collected on 79 plots in Montana, Wyoming, and Colorado. The average proportion of trees visibly infected in reproduction 10, 15, 20, and 25 years old was 3, 9, 18, and 32 percent, respectively. The amount of dwarfmistletoe was highest in reproduction on the better sites. The average maximum distance of infection into reproduction from the infected residual stand was 26 feet. Dissections of the oldest infections on the plots showed that 14 percent of the stands that had dwarfmistletoe were infected before they were 4 years old, and 84 percent were infected before they were 11 years old. None of the factors measured on the residual stand or at the location of the study area were correlated with amount of infection in the reproduction.

A fungus parasite of dwarfmistletoe (Colletotrichum gloeosporioides) caused considerable damage to Arceuthobium campylopodum f. campylopodum in an uneven aged ponderosa pine stand near Spangle, Washington. A survey revealed that 75 percent of the dwarfmistletoe infections were attacked by the fungus.

Field tests over the past 5 years in California show that treatment of dwarfmistletoe in pine by direct spraying with an ester formulation of 2, 4, 5-trichlorophenoxybutyric acid is notably selective and effective.

Studies in California on the biology of dwarfmistletoe in pine show that a proper balance of temperature and light are needed for success in controlled inoculations. Few infections occurred when temperatures exceeded 80°F.

Greenhouse inoculations show that ponderosa pine from the Black Hills of South Dakota is susceptible to Arceuthobium vaginatum. The absence of the parasite from South Dakota and Wyoming is probably caused by climatic factors.

Preliminary results from a series of inoculations with the lodgepole pine dwarfmistletoe indicate that it has an incubation period (time from inoculation until emergence of the first shoots) of from 2 to 5 years. About 80 percent of the plants first produced shoots 3 or 4 years after inoculation. Knowledge of the incubation period is important in timing the followup operations in mistletoe control projects.

Bristlecone pine was found to be attacked by two species of dwarfmistletoe in Colorado: Arceuthobium americanum and A. vaginatum f. cryptopodum. Neither species had been previously recorded on this host. Bristlecone pine seems to be particularly susceptible to A. americanum because several heavily infected trees and some killed by it were found.

Four dwarfmistletoes common to southwestern United States were collected on a trip into Mexico: A. douglasii, A. campylopodum f. blumeri, A. vaginatum f. crypopodum, and A. gillii. Two species, A. verticilliflorum and A. abietisreligiosae, which had been thought to be synonymous with A. vaginatum, were found to be valid species. A number of undescribed species were also discovered.

The dwarfmistletoe that attacks Chihuahua pine in Arizona and northern Mexico has been described as a new species, Arceuthobium gillii.

The number of collections in the Fort Collins Mistletoe Herbarium was practically doubled in 1963 with the addition of 726 specimens, bringing the total number of sheets filed in the Herbarium to 1,480. Approximately two-thirds of the specimens are Arceuthobium and one-third Phoradendron.

f. Heart rots. Wood taken from cherrybark oaks growing on rich loessial soils and on adjacent poor ridgetop soil was inoculated under controlled conditions in the Stoneville, Mississippi laboratory with Pleurotus ostreatus. The rate of decay, expressed as loss in weight, was significantly greater for the wood from the poor site. These results substantiate observations that heart rot in standing trees generally is greater on poor than on good sites.

A total of 113 commercial-sized aspen bearing Fomes igniarius sporophores were dissected on 11 areas on 5 National Forests in Colorado. Average length of decay above and below the highest and lowest sporophore was 12.0 $\pm$ 0.7 feet. Estimated board-foot cull for an individual tree with 1 to 3 sporophores at any height, or any number of sporophores 0 to 16 feet on the bole, is 59 $\pm$ 3.2 percent (20 $\pm$ 1.6 percent cubic-foot cull). A tree with sporophores not in these two classes should be considered a total cull.

4. Foliage Diseases

a. Elytroderma needle blight. Life cycle studies by cooperator at Montana State University on Elytroderma deformans, which causes systemic foliage and twig diseases of six species of pines, revealed several unknown anatomical features about the ontogeny of the imperfect and perfect stages. The following ontogenetic sequence was determined. The undulated systemic hyphae in the phloem of the stem, terminal buds, current and second-year needles are multinucleate. By continual differentiation, the hyphae which invade outward from the phloem area of second-year needles to the hypodermal layers initiate the conidial stage with uninucleate hyphae. The perfect stage, which is usually initiated after the imperfect stage, is formed from binucleate hyphae. The perfect stage (hysterothecium) is shown to be a loculated stroma during its early ontogeny.

b. Emergence tipburn of eastern white pine. In controlled experiments with this disease it is necessary to be able to produce ozone at will. Many oxidant generators, however, produce large amounts of nitrogen dioxide in ambient air as well as ozone. Tests were made at the Southeastern Station with two such generators, and both produced several times as much NO_2 as O_3. To avoid the production of NO_2, it is necessary either to pass only oxygen through the generator, or to use a generator that will not produce NO_2 in ambient air. In the former method, necessary equipment is frequently too expensive for limited exposures. It was found, however, that the small and inexpensive G4S11 (General Electric) ozone bulb does not form significant amounts of NO_2. It is necessary only to provide air circulation within a closed chamber by means of a small fan or blower while irradiating with one or more G4S11 lamps to obtain sufficient O_3 for many purposes.

c. Post-emergence tipburn of eastern white pine. This disease is particularly conspicuous in areas around coal-burning power plants. No pathogenic organisms have been found, and neither pruning nor fertilizing has brought about recovery. Trees transplanted out of the affected area recovered, while trees transplanted within the affected area continued to decline.

Trees differ greatly in their susceptibility to the disease. Scions from susceptible trees continue to display symptoms year after year even when grafted to resistant trees. Scions from resistant trees continue to be disease free year after year even when grafted to diseased trees. The grafting experiment furnished evidence that a virus was not involved and indicated that the cause of the trouble is an atmospheric agent. Members of susceptible clonal lines potted with the same soil mixture were injured when placed in the affected area, while others remained

"disease-free" outside. This use of susceptible clones as biological indicators gives further evidence that the causal agent is atmospheric and that the level of resistance is genetically controlled.

d. Chlorotic dwarf and eastern white pine. In 1959 surveys for chlorotic dwarf in Ohio pine plantations showed a greater incidence of infected white pines near pollution sources. Two years later, 175 5-year-old diseased trees were potted and removed from the affected area to a pollution-free environment to observe changes in symptom expression. Although these infected pines varied in their initial severity of symptom expression, all trees appeared to recover within a year after transplanting, whereas check trees in the affected area remained symptomatic. During the past 2 years, recovered potted trees have been returned to planting sites near industrial installations and many of them now display symptoms of mottling and premature defoliation characteristic of the chlorotic dwarf disease.

A study is underway in Ohio to determine if aging influences the susceptibility of needles on chlorotic dwarf pines to air pollutants. For this purpose plastic bags were placed over shoots of diseased trees in the field prior to bud break and removed at periodic intervals thereafter. Newly formed needles showed no symptoms while covered. When the bags were removed, symptoms appeared after different periods of time, varying with the age of the needles at the time the bags were removed. Shoots unbagged late in the year required a longer period of exposure to the contaminated atmosphere for needle mottling symptoms to appear than those unbagged earlier in the season. Shoots exposed in early fall failed to develop any symptoms. The principal period of susceptibility to mottling appears to be confined to the early part of the season, the period of most active plant growth.

e. Pine twist rust. Seedlings of Douglas-fir and 6 species of North American pines have been proved susceptible to pine twist rust in a study in Italy. Eleven foreign pines, including a white pine, and European larch are also susceptible. Potential hosts for this destructive disease include our valuable hard pines, white pines, larch, and Douglas-fir. Our widely distributed aspens and poplars can serve as alternate hosts, indicating the need to exclude this pathogen. (PL-480)

f. Miscellaneous. The perfect stage of Cercospora magnoliae, the causal agent of a damaging leaf spot of Magnolia grandiflora and M. virginiana, was discovered and named Mycosphaerella millerii n. sp. The discovery of the perfect stage completes the knowledge of the life history of this fungus.

The fungus causing the red band foliage disease of ponderosa and lodgepole pines was described as a new variety, Dothistroma pini Hulbary var. linearis by cooperators at Washington State University. Actinothyrium marginatum Sacc. is considered a nomen confusum. Identifications of D. pini var. linearis as Lecanosticta acicola (Thum.) Syd. are considered erroneous.

Needle blight caused by Dothistroma pini is an important disease of pines in the Great Plains. In preliminary tests, Bordeaux mixture provided excellent control in an Austrian pine plantation in eastern Nebraska, being far superior to Puratized Agricultural Spray, Zineb, or Captan.

About 20 common needle cast fungi were collected in Colorado. Hypodermella concolor, a parasite of lodgepole pine, was by far the most widespread. An undescribed species of Lophodermium was discovered on ponderosa pine. Hypodermella arcuata was found for the first time on limber pine.

Of the 500 pathogens of pine and fir collected and identified in Spain, those potentially most serious to U. S. trees are on needles. A species of Niptera, a genus unknown among tree pathogens in North America has been found and described and its pathogenicity is under test. (PL-480)

A serious leaf, twig, and fruit rust, known only in the Orient, was found on a species of Acacia in Taiwan. (PL-480)

5. Systemic Diseases

a. Oak wilt. The cooperative Oak Wilt Post Control Appraisal study was completed except for final summarization and publication of results. The percentage of treated plots on which oak wilt spread was prevented by the various control treatments was - 3 percent in Kentucky, 9 percent in North Carolina-Tennessee, 21 percent in West Virginia, and 33 percent in Pennsylvania. Of particular interest was evidence that oak wilt is much more virulent and severe in an area in northeastern West Virginia, western Maryland, and south-central Pennsylvania than elsewhere in the study States.

New tests, in which oak wilt infected red oak logs were fumigated with methyl bromide under a plastic tarpaulin, were completed by the Central States Station. In these tests the ends of all logs were coated with a latex paint mixture impervious to methyl bromide. The fungus could not be isolated from the fumigated logs but was recovered from all check logs. These results strengthen confidence in this treatment and indicate that the fumigant penetrates the bark readily so log length should not be a factor in treatment effectiveness.

Studies in Missouri were continued to determine the importance of the small oak bark beetle in spreading oak wilt. Using the spermatization technique, it was found that of a thousand beetles collected individually in gelatin capsules from five wilt-killed trees, 28 percent were contaminated with the fungus. Both "A" and "B" compatability types of the fungus were found among the beetles emerging from two of the five trees; however, no single beetle from either tree was found to be contaminated with both types.

In southeastern Minnesota and central Wisconsin 42 percent of the surveyed oak wilt infection centers have increased in size annually. The average rate of increase was 3.2 feet per year. New center establishment was 1.7 for each 100 acres of type samples. Enlargement and establishment rates could not be correlated with stand and site factors.

Two types of color film were used in a test in the Southeast to determine if aerial color photography would be feasible for oak wilt surveys. Little improvement in accuracy of locating wilting oaks could be shown over present observation methods. Since cost was almost 20 times as great, aerial photography is not recommended at this time.

b. Sugar maple dieback. Over 2,000 sugar maple trees have been evaluated individually each year since 1958 in a study of dieback in the northern hardwood type of Upper Michigan. Dieback increased each year with most of the increases in the larger size classes and damage greatest in heavily cut and less in moderately cut stands. Larger trees (15+"d.b.h.) were most severely affected with about 50 percent showing symptoms, while only 7 percent of the pole-size trees (5-9"d.b.h.) were affected. Nearly all affected trees have less than one-half of the crown involved, and fewer than 1 percent have died since 1958. Unfavorable climatic conditions have been postulated as a possible cause.

Sapstreak disease of sugar maple was first discovered in the Lake States in 1960. During 1962 several new cases were found. The disease does not appear widespread or prevalent at present, but may be potentially dangerous. In one stand closely examined following logging, nearly 10 percent of the trees cut were infected. There is strong circumstantial evidence indicating that the causal fungus enters through wounds on healthy trees.

A severe outbreak of a new Fusarium wilt of Acacia was found in Taiwan that could be catastrophic if spread abroad. (PL-480)

6. Decays of Wood and Wood Products.

a. Decays of killed timber. A 12-year summary was made of the rate of deterioration of Engelmann spruce killed by the spruce beetle during a major Colorado epidemic from 1941 to 1952. As estimated 4.3 billion board feet of Engelmann spruce and lodgepole pine was killed. In stands where only spruce was killed, which includes most of the area, it is estimated that about 33 percent of the original cubic foot volume is lost 20 years after the date of kill. About one-third of the loss is to decay in standing trees and two-thirds to windthrow. It is anticipated that windthrow will be a progressively more important deterioration factor in the future.

b. Decay of raw products. Logs of four southern species were stored for 3 and 11 month periods starting in July, under water sprays. After 16 weeks the logs under water sprays were essentially free of stain, decay, and end checks. The untreated controls were heavily damaged. At the end of 11 months, lumber cut from the logs showed the following losses due to degrade: untreated controls 100%, hackberry 14.3% and other three species 0.3 to 1.9%. Approximately equal effectiveness was attained by continuous spray, 12 hours on during the day and 12 hours off at night, and 30 minutes on and 30 minutes off around the clock.

While storing logs under water sprays now is common practice, recent studies in the South suggest some disadvantages to this type of storage. Pine and gum logs under longtime storage, even though relatively free of typical stain and decay, were heavily infected with Fusarium and other imperfects and with bacteria. Pine so infected is highly absorbent. More information on the effects of these organisms on wood properties is needed before water sprays can be recommended without reservations.

A major accomplishment at the Forest Products Laboratory was the completion of a study of bacterial infection of wood, culminating more than 3 years' work. Investigation has disclosed that many bacteria common to soil and water can invade and substantially increase the porosity of wood by opening up the rays and by destroying pit membranes. Bacteria must now be recognized as major invaders of wood in wet situations, and by controlling them wood products may be improved for uses in which low absorptivity is important.

Additional evidence was obtained at the Forest Products Laboratory than the varied nonfungus, or chemical, discolorations resulting in damage to hardwood lumber and veneer during seasoning are caused by a reaction between oxygen in the air and components of the wood. Preheating the wood before drying it prevented discoloraction in some cases, probably by destroying oxidizing enzymes. These findings can now be projected into commercial trials of control measures, which if successful should be of considerable help in holding or even expanding certain hardwood markets. For example, stem heating at 212° F. for 30 to 60 minutes was largely

found to preclude development of chemical stain in sweetgum but only slightly reduced discoloration in sugar maple. A difference in mechanisms of the oxidation discoloration between the two woods is thus indicated. Additional evidence was obtained that an oxidation reaction, requiring the presence of oxygen, is the basic cause of discoloration. Oxidizing enzymes frequently appear to be involved.

Progressive stages of white rot and brown rot were observed and photographed in microscopic detail at Madison. The decrease in cellulose resulting from decay was determined, both in microtome sections and in macerated samples, by the birefringence of the cells when observed between crossed polarizing filters. Various histochemical tests for detecting chemical changes were found. Alterations in lignin content of the cells could be detected by changes in absorption of specific ultraviolet wavelengths. Procedures were devised for characterizing many of these changes quantitatively.

c. Decay of wood in use. Southern studies show that width of eave is the most important single factor affecting rainwetting. The use of an eave gutter added little to the effectiveness of roof overhang beyond the amount that the gutter increased overhang. The peeling of thick paint films cannot be prevented by in-place water-repellent treatments.

d. Natural durability. Laboratory studies at Dehra Dun, India have shown that native sal (Shorea robusta) is highly resistant to decay, in the same durability class as our black locust and redwood. Studies are underway to determine the factors responsible for this resistance to decay. Similar tests are being conducted on 11 other species of Indian woods of potential importance in world commerce. (PL-480)

e. Causal fungi and their identification. Ceratocystis virescens and C. coerulescens, two important blue-staining fungi, are difficult to distinguish taxonomically on basis of their morphology. Basic laboratory studies at the Laurel Laboratory are finding cultural and physiological means of separation while exploring the precise manner in which staining is brought about. Rate of growth on different media at different temperatures is characteristic for each fungus.

During the year 356 cultures of suspect wood decay fungi were received for identification at the Laurel Forest Disease Laboratory. Of these 155 were woodrots and identified to species. The Laboratory also sent out 409 isolates of fungi in pure culture, representing 157 species, in response to requests.

The Herbarium was brought to 13,763 specimens by the addition of 506 fully processed specimens during the year.

The Reference Culture Collection maintained at the Laurel Laboratory was enlarged by the addition of 881 cultures, including 68 new species, and 542 new haploid isolation, representing 32 species. Preliminary study was made of 250 newly acquired fresh isolates from Costa Rica, including many never before placed in culture. Many are subtropical species also native to the southern United States.

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IV. FOREST PRODUCTS AND ENGINEERING RESEARCH

A. FOREST PRODUCTS UTILIZATION RESEARCH

Problem

The timber-using industry is an important part of our present economy. In 1960, nearly 6 percent of the Gross National Product, or about $25 billion, originated in timber-based economic activities. Utilization problems, however, are especially acute on the considerable acreage of timber in small ownerships where continued harvesting of the better timber has resulted in residual stands of low value under present use standards. Research is needed to develop uses for this presently unmarketable timber.

Although the timber industry conducts a substantial amount of research, it is a complex of many small companies and lacks the unity of other basic industries, such as aluminum, steel, plastics, and petroleum. Unlike the timber industry, these competing industries are generally comprised of a few giant corporations, several of which employ more researchers than the entire timber industry.

The Federal Government has a strong interest and responsibility in forest products utilization research. Because few of the forest products companies are financially able to support a research program, the industry relies on the Federal Government for research assistance. Not only is research in forest products utilization essential to give stability to the present industry but also to develop a technical basis for new product manufacturing and marketing.

USDA and Cooperative Programs

The Department has a continuing long-term program, involving both basic and applied research, to promote better utilization of the Nation's timber resource. Wood utilization research currently centers on increasing the serviceability of wood products, on developing new uses for wood, and on improving its quality.

Research is underway to evaluate the intrinsic wood quality of standing timber, establish what effects such environmental factors as soil and rainfall and such silvicultural treatments as pruning have on quality, investigate by microscopic and other means how the physical structure of wood is related to its properties, and assist in the establishment of quality grades for trees and logs.

The processes and treatments by which wood is made serviceable, from the cutting of the round logs to the utilization of sawdust and other processing residues, come within the scope of research on solid wood products. Included are the many kinds of operations involved in the processing and protection of wood in its solid form. The production of lumber, veneer, plywood, laminated wood, and particle board; product and process development; machining operations; preservative and fire-retardant treatments; painting and finishing; glues and gluing techniques; and seasoning operations comprise the principal processing investigations under study.

With wood the chief source of fiber for myriad pulp and paper products, the demand for which continues to increase, an intensive program is being carried out on pulping processes and pulp properties, on wood fiber properties related to pulp and paper production, and on the manufacture and properties of paper products.

Primarily, this research is aimed at extending pulping processes to previously unused species and qualities and to produce more pulp from less wood.

Production of chemicals from wood requires basic studies on the chemistry of wood carbohydrates, the structure and chemical behavior of lignin and the extractives of wood and bark, the biochemistry of wood constituents and their microbiological conversions, and the surface and polymer chemistry of wood. These studies not only provide basic knowledge essential to the development of broader industrial chemical conversion of wood, but also a basis to determine fundamental relations between chemical and other wood properties, such as strength and factors affecting strength, preservative treatment, seasoning, dimensional stabilization, and finishes. Also, a pioneering research unit established in 1963 at the Forest Products Laboratory, Madison, Wisconsin, is studying the fundamental aspects of lignin chemistry.

Current research in wood engineering deals with the investigation of the mechanical, physical, and related properties of wood and wood-based products; including plywood, particle board, laminated wood, chemically treated wood, and composition board materials. Increasingly important, however, is research on the use of wood in housing, farm structures, other light-frame buildings, and the broad field of packaging. Here studies are underway on the development of mathematical and theoretical concepts for the behavior of wood and wood-base materials under stress. Also, studies are underway on the establishment of design and performance criteria for more effective use of wood and wood-base materials as structural components. A poineering research unit, established in 1963 at the Forest Products Laboratory, Madison, Wisconsin, is concerned with the use of analytical mechanics techniques for interpreting experimental data.

Although the Forest Products Laboratory is a focal point for nationwide wood research, the mammoth task of dealing with regional and national wood utilization problems also involves work at the regional Experiment Stations. Forest utilization research within the Station organization is attuned primarily to the needs of the region. In many of its studies the Station seeks the help of the national Forest Products Laboratory, and also cooperates with university or industry research agencies in seeking solutions. The regional staff of wood utilization scientists also provides consultation and advice to industry and extension agencies, and maintains close liaison with non-Federal research groups and the Forest Products Laboratory. The Station thus acts as an exchange point between research and problem areas, adapting Forest Products Laboratory results and possible solutions to technical difficulties encountered by the woodland owner or the wood-using industry.

Similarly, the experience and knowledge of scientists at the regional Experiment Stations and at the Forest Products Laboratory have proved invaluable in connection with technical reviews of proposals submitted for consideration under the Rural Areas Development efforts of the Department of Agriculture, often in connection with proposals for industrial developments submitted to the Area Redevelopment Administration of the Department of Commerce.

Research at the Forest Products Laboratory and at the regional Experiment Stations is extended, where suitable, through cooperation with universities, other Federal or State Government agencies, private laboratories, professional societies, industry associations, or with industrial companies. Likewise, cooperative research may be done for industries or private individuals where its accomplishments tie in and will benefit the planned research program. During the past year cooperation has been with 17 colleges and universities, 29 Federal and State Government agencies, 30 industry associations, several private laboratories or professional societies, and approximately 100 private companies.

Federal scientific effort devoted to research in this area now totals about 183 professional man-years. Of this number, 44 are devoted to regional utilization problems at the Forest Experiment Stations and the Institute of Tropical Forestry, and 139 are at the Forest Products Laboratory. Of the latter, 23 are in the field of wood quality, 40 in solid wood products, 12 in wood fiber research, 30 in wood chemistry, and 34 in wood engineering research. Involved are some 20 scientific disciplines in areas of chemistry, engineering, mathematics, physics, and biology.

Research in this field is also performed by state laboratories such as those in Oregon, California, and Texas and by numerous schools. Substantial research is now going forward in industry-supported laboratories and those of individual companies. It is estimated that the total industrial research effort in this field involves the equivalent of about 2,000 scientific man-years; and that performed by public agencies outside the Federal Government about 100 man-years. Industry research is performed largely to obtain competitive advantage and is generally not freely available.

A program of research in foreign countries has developed under Public Law 480. Currently eight projects are underway involving about 20 professional man-years per year. One project in Peru involves collection of authentic herbarium samples and wood from Peruvian trees. Four Finnish projects are on factors affecting impregnability of wood, aerobic bacterial degradation of lignin, accessibility studies of cellulose fibers, and moisture-temperature-time relations as they affect wood strength properties. One project in India involves working qualities of Indian timbers. Two projects are located in Pakistan. One involves the factors influencing the absorption and penetration of preservatives in tropical woods and the other is concerned with collecting wood samples and herbarium materials in East Pakistan.

In international cooperation, the Forest Products Laboratory was host to conferences of two international organizations--the United Nations FAO (Food and Agriculture Organization), and Section 41, Forest Products, of the IUFRO (International Union of Forest Research Organizations). Some 60 delegates from 32 foreign nations participated in one or both. IUFRO's function is to foster exchange of information and closer relationships between scientists with common interests and problems. FAO's main purpose is to gather scientific and technological information and make it available to UN member nations to help them develop their timber resources.

Program of the State Agricultural Experiment Stations

Forest products utilization research is active in a variety of subject areas at the state agricultural experiment stations. Projects are addressed to study of structure and properties of wood and their relation to tree growth, improvement in products and in processing procedures, development of uses for low-grade wood and wood residues, improvement in wood rigid frame design and strength of joints, improvement in wood seasoning, durability and preservation, studies of permeability to water vapor of materials used in wood finishing, fundamental study of wood moisture relationships, utilization of residues, and improvement in methods for structural lumber grading.

A total of 18.7 professional man-years is being devoted annually to forest products utilization research at the state agricultural experiment stations.

Progress--USDA and Cooperative Programs

1. Wood Quality

a. Wood structure and identification. The seemingly simple task of identifying wood and wood products continues to be an important service performed by the Forest Products Laboratory. Last year it included such strange material as archeological specimens from Guatemala, Greece, Turkey, and Iran, consisting of decayed wood, charcoal, and metal-encrusted wood. Perhaps the smallest specimen ever submitted for identification was one from the Yale University Department of Biology which was found during excavation of Mayan ruins in Guatemala. This specimen measured 250 microns in length and about 30 microns in width and was identified to be the epidermis of a monocot leaf.

b. Fine wood structure. Photographic evidence that lignin softens and flows when wood is heated was obtained by a researcher doing advanced study in electron microscopy while in Europe under authority of Public Law 85-507. His research was done at the Institute for Forestry Research, University of Munich, Germany.

It has long been assumed that the lignin is plasticized when wood is heated or compressed. This accounts for the fact that wood remains in a compressed state after the compressive force is released.

Electron microscope studies have shown that the inner surface of the cell wall has a wartlike appearance. These warts are thought to consist largely of lignin, as are the lignin-containing toruses that screen the pit openings in cell walls.

Electron microscope examination of wood samples that had been heated to 190°, 200°, and 240° C. in a thermogravimetric balance without air for 2-1/2 hours clearly showed that both the warts and the toruses liquefy and flow. At these temperatures, the cellulose appeared to be unchanged.

These findings lead to interesting speculation. Since lignin softens before heat affects cellulose, it appears to have a protective as well as an adhesive role in wood. It is possible, therefore, that further research may lead to more effective fire retardants chemically designed to inhibit the softening of lignin and thus modify pyrolysis and combustion processes.

c. Wood structure-wood property relations. Studies of factors affecting lumber grade and yield recoveries showed that compression wood occurring in green studs correlated well with that identified on the log ends, thus indicating that compression wood occurrences in loblolly pine lumber can be predicted reliably from examination of log ends.

Data for regression-correlation analysis substantiated the earlier information that resistance to crushing and the related modulus of elasticity along the grain was closely correlated with specific gravity of the wood and with the angular orientation of fibrils in the secondary walls of summerwood fibers. In all softwoods, large fibril angles of 20 degrees or more are associated with compression wood and excessive longitudinal shrinkage, erratic bending properties, and markedly inferior end-crushing and stiffness. But even in the absence of such aberrant fiber structure, large fibril angles occur in the lower trunks of portions of some vigorously growing southern and western yellow pines. In loblolly pine, for example, large fibril angles were closely correlated with exceptionally low strength and stiffness regardless of whether the wood was low or high in density.

d. Environmental, growth, and silvicultural effects. A study designed to develop sampling procedures and to evaluate environmental effects and silvicultural practices showed a high degree of correlation between the rate of change in the characteristics of the latewood growth and the magnitude of soil water deficits for the June-October period. The basic patterns were accentuated by abundant moisture and became much less evident under drought conditions. Age of the tree was also found to be important, the older trees showing less variability throughout the length of the annual growth sheath.

e. Wood quality evaluation and genetic effects. Over the past 3 years, specific gravity has been determined for 50,000 increment cores systematically collected by the Forest Survey. Destructive sampling of almost 2,000 trees provided the means of converting the increment core specific gravity into an estimate of tree specific gravity.

The relationships of specific gravity to strength properties and to fiber yields have aroused much interest among industry people. The high correlation of density to pulp yields has direct application to the pulp and paper industry where much pulpwood is now purchased on a weight rather than volume basis. More specific information on density of timber and variation patterns in density will be extremely helpful in further developing the use of wood as a stress-graded engineering material in the form of lumber, laminated beams, or plywood.

During this year, Western Wood Density Survey preliminary results became available. Complete sets of 30,000 punched data cards were also furnished to each cooperator and western Forest Service Experiment Stations. Wood processors who have already found survey information of value include utility pole and piling producers, laminators, and pulp manufacturers. In the West, pole producers want trees with thick sapwood bands, since heartwood of Douglas-fir and some other common pole species is difficult to treat with preservatives. Laminators need material meeting exacting specifications for strength and stiffness, and survey findings help them locate likely sources of it. Most pulp manufacturers want dense wood because it yields more fiber.

Studies at the Institute of Tropical Forestry on specific gravity of plantation mahogany show that rapid-grown plantation mahogany can be a valuable addition to the forest resource of Puerto Rico. Density measurements of plantation trees fall within the denser portions of the range of values reported for wood in the natural forests and, in this respect, the local wood is not inferior to that imported.

Research at the Rocky Mountain Station on density of lodgepole pine showed that the average whole tree specific gravity was 0.394 based on 444 randomly selected trees. The previously published value for the species is 0.380. Specific gravity determinations, taken at prescribed intervals along the length of the bole, showed that the specific gravity at breast height (0.393) is highly correlated with the average for the whole tree. The average specific gravity was found to decline rather sharply up to 10 feet in height and then more gradually up to 20 feet. There was little or no change between 20 and 50 feet in height.

f. Log and tree grade development. A review of the Log and Tree Grade Research Program was made by the Washington Office. This was the first review of the total program (six projects) since its establishment in 1958. The initial aims and objectives were found to be valid and progress was considered to be substantial. A need was found for broadening project programs to include long-term aspects of quality problems. Specific recommendations were made, accordingly, for a more balanced and strengthened program, consistent with the total needs.

Yields, in terms of lumber grades and value, were determined for upper-quality hardwood logs. These yields will help sawmill operators in deciding whether the veneer quality logs should be sold or converted into lumber. A grading system for hardwood veneer was developed as a criteria for evaluating veneer yields from logs leading to the future development of a grading system for hardwood veneer logs.

Lumber recovery studies at the Central States Station furnished lumber grade yield data for use in value determinations for hardwood logs of 10 species. These studies show that bird peck on large size yellow poplar and epicormic branches on black cherry and soft maple can be considered "no defect" when grading logs of these species.

At the Pacific Southwest Station, a guide was developed for field use of an improved system for grading ponderosa pine and sugar pine sawlogs in trees. Another completed study provides a standard procedure for recording log-surface and log-end characteristics for use in developing log or tree grading systems.

At the Rocky Mountain Station research showed that the improved ponderosa pine log grades were effective in separating Black Hills ponderosa pine logs into quality classes and were easy to apply. Lumber yields of approximately 25 percent in grades 1 and 2 common, 30-35 percent in grade 3 common, and 30 percent in grade 4 common can be realized from average quality sawtimber stands in the Black Hills.

A tentative grading system (3 grades) was developed at the Pacific Northwest Station for inland Douglas-fir trees from four states. This system is easier to apply to logs in standing trees than present grading systems and greatly reduces the unexplained variation in value.

Meanwhile, studies at the Northeastern Station of old-growth eastern white pine logs in the Lake States and southern Appalachians, showed significantly lower lumber value yields than comparable grade logs from younger stands. This was due to the higher incidence of red ring rot and indicates a possible need to modify the log grade specifications to reflect this lower performance.

g. P.L. 480 - Peru. The collection of wood and herbarium material from the trees of Peru included complete herbarium material of 69 tree species and wood from 12 species. Of the 69 species received to date, 6 species and 1 variety are new to botanical science. Four additional specimens are being studied by specialists and may be described as new after critical study. One of the trees collected near Iquitos, Peru, was found to be a new species of Virola and was named Virola kukachkana, in recognition of the work by Dr. B. Francis Kukachka of the Forest Products Laboratory, by Dr. L. O. Williams of the Chicago Natural History Museum.

h. P.L. 480 - Pakistan. A project to collect authentic wood samples and herbarium materials of trees in East Pakistan was activated at the East Pakistan Forest Research Laboratory, Sholashahar, Chittagong. The work was reviewed on the ground by a representative of the U.S. Forest Service.

2. Solid Wood Products

a. Machining and veneer cutting. Research on the effects of growth rate on the use of softwoods for veneer shows that southern pine, now emerging as a structural plywood species, compares favorably with Douglas-fir as a veneer wood because of similarities in the characteristics of springwood and summerwood in the two species types.

An exploratory study to investigate the use of Nepal alder from Hawaii for veneer and plywood revealed that the species is suitable for cores, crossbands, and backs, but is too soft for face veneers.

New research in veneer cutting has demonstrated that precompressing flitches reduces knife checks in pieces sliced from the wood. A systematic study of this phenomenon should supply valuable background information for improving cutting techniques. At the Southern Station three unconventional headrig designs capable of forming heart-center cants for producing slicewood from boltwood (See also IV A 2 d) were invented and tested. The headrigs produce no sawdust. A single 12-second operation makes an accurately sized, heart-center, S4S cant plus pulpable chips (or flakes for flakeboard). Related work at the Forest Products Laboratory is continuing to develop a new "slicewood" machine that will be suitable for the proposed new conversion system.

b. Wood drying. A study of strains developed in drying ponderosa pine showed that a major cause of surface checking is delayed tensile strains in the sapwood of boards containing both sapwood and heartwood. A 6-hour conditioning at the end of drying provided satisfactory stress relief. Basic drying stress data of this kind will ultimately lead to improvement in the current drying and conditioning processes for softwood lumber. Progress has been made in devising equipment to obtain constant flow rates needed in determining permeability of green wood. After basic permeability has been measured, the effects of preliminary treatments, such as steaming and chemical reactions, can be gaged. In the completion of a study on the basic mechanism of high-temperature drying, studies of drying lumber at temperatures above the boiling point of water showed good correlation between predicted and actual heat transfer values. This substantiates the basic theory from which more efficient commercial drying processes are expected to be derived.

An investigation of high-temperature drying of softwood studs at Intermountain Station showed that a large commercial kiln of this type can perform well and has promise for wider use in drying dimension lumber. Analysis of lumber degrade produced by the high-temperature process in comparison with that produced by conventional kiln drying showed that, in this respect, there was no overall net difference in results.

High-temperature drying produced less warp but more surface checking and degrade due to knotholes. Potential industrial savings from high-temperature drying are large, because of great savings in time. A comparison of high-temperature drying of aspen and yellow poplar revealed that they dry in a similar manner.

At the Institute of Tropical Forestry solar drying experiments showed that drying rates are almost identical during the winter and summer months. Solar drying of 8/4 mahogany lumber is twice as rapid as air seasoning; 4/4 boards can be dried in almost 1/3 the time (to a moisture content of 20 percent).

Meanwhile, research at the Southeastern Station of the surface checking of white oak, as related to mechanical processing, showed that checking of the lumber during drying is greatly reduced by surfacing the lumber when green. Even a small amount of green surfacing (1/32 inch) reduced surface checking significantly. Fewer surface checks were found in bandsawn lumber as compared to circular-sawn material. This practice could result in improved kiln schedules and improved performance of paints and lacquers on finished products.

Also at the Southeastern Station a study of polyethylene and kraft paper wrappings, for protecting kiln-dried lumber stored in the open, showed that moisture content of lumber increased as length of storage time increased, even though moisture regain was somewhat retarded by the coverings. The stickered lumber piles, shrouded with polyethylene film, and the solid-stacked lumber, completely wrapped in kraft paper, were most resistant to weather changes and moisture pickup. However, the range in moisture content between the driest and wettest boards was relatively the same within all lumber piles regardless of the treatment. Wet spots, stains, and even incipient decay occurred in some of the test piles.

c. Glues and gluing processes. Research on the chemical reactions between glues and fire retardants indicate that the difficulties encountered in gluing wood treated with retardants stem from interactions between ammonium ions and formaldehyde in the glue.

Meanwhile, experiments on the durability of a new nylon-epoxy resin adhesive in wood-to-wood joints showed that the durability of the new adhesive may be adequate where conditions of exposure to moisture are mild.

Continuation of studies on gluing southern pine veneer showed that at least one conventional phenol-resin glue used for Douglas-fir plywood can produce exterior-type pine plywood, although some minor changes in gluing conditions may be necessary. One extended phenol resin and one blood-phenol resin glue met the interior type tests on pine, and one protein-blend glue was marginal in these tests.

d. Glued wood products. Southern pine plywood, made by modern commercial processes, became a reality in February 1964, partly through the assistance of forest products research and technical aid at the Southern Station and the Forest Products Laboratory. The first car of sheathing-grade plywood was shipped from Fordyce to Little Rock, Arkansas, inaugurating a new industry using the products of southern forests.

Commercial Standard 259-63, Southern Pine Plywood, became effective November 15, 1963. Modifications in the Standard are under consideration that will enable the industry to guarantee that the product is equivalent in strength to other softwood plywoods presently manufactured. Quality will be certified by the American Plywood Association's new laboratory at Shreveport, Louisiana.

At the Southern Station a study on the use of southern pine boltwood for beams showed that it is technically and perhaps economically feasible to manufacture long, laminated, structural beams from thick veneers sliced from southern pine boltwood. Beams of relatively uniform high strength were obtained by locating each lamination according to its stiffness. Stiffest pieces formed the top and bottom of each beam; least stiff were centrally located. Heart-center cants were sawn through-and-through to produce 7/16-inch-thick veneer. The veneer pieces were dried and double-surfaced to 1/3-inch thickness to simulate "slicewood."

e. Wood finishing. Experiments designed to measure the effects of ultraviolet rays on wood showed that success in developing longer-lasting paints and other wood finishes for outdoor use will hinge largely upon improving the protection they give from the ultraviolet portion of sunlight. Microscopic examination revealed that the surface fibers directly underneath a varnish finish exposed to ultraviolet rays deteriorated seriously. Checks and splits developed around bordered pits (microscopic openings) in the walls of springwood fibers and spirally in walls of summerwood fibers. Separation of fibers from one another was also observed. Walls of some cells were seriously damaged. While these injurious effects were sustained

under severe laboratory conditions not directly related to normal outdoor weathering, they are indicative of what sunlight can do over a period of time. The resulting strains, although microscopic in size, are capable of imposing stresses severe enough to cause premature coating failure.

Other experiments on the photochemical actions induced by ultraviolet light when it strikes wood revealed that significant amounts of carbon dioxide, carbon monoxide, and methanol were produced by the irradiation. Analysis of the wood after exposure to this radiation showed that its methoxyl content was significantly lowered in an atmosphere of nitrogen gas, photochemical and oxidation reactions were greatly reduced, and the irradiated wood was considerably less acid. Microscopic examination of the wood showed that the most serious damage was sustained by the walls of ray cells.

Evaluation of various finishing systems under longtime outdoor exposure continues to yield useful information on painting systems. Of particular interest is the continued good performance of three-coat painting systems, now 8 years old, on southern pine boards overlaid with resin-treated paper.

Meanwhile, studies of the treatment of wood surface with inorganic chemicals to improve surface properties showed that certain inorganic compounds, particularly copper, chromium, and mercury compounds, are effective surface treatments in retarding loss of wood substance in weathering and improving performance of exterior clear finishes.

f. Fire performance of wood. Experiments on the performance of wood in fire showed that wood chemically treated with fire retardants chars more and gives off less flammable tar than untreated wood when heated. Wood containing 6 percent by weight of diammonium phosphate, for example, produced from 20 to 45 percent more protective char and from 17 to 55 percent less flammable tar than untreated wood when heated for 2 hours at 350° C. The experiments were performed in an inert atmosphere of helium gas, so that all byproducts of heat could be recovered and analyzed. In addition to wood, the experiments were conducted on alpha cellulose and lignin in order to compare the decomposition characteristics of these two major chemical components of wood. The cellulose began to decompose chemically at a lower temperature when treated with fire retardants than when untreated.

Continuation of experiments on THPC-resin (a fire-retardant treatment developed for fabrics by Southern Regional Laboratory, ARS, in cooperation with a chemical company), show promise when the resin is used as a treatment for reducing the ignition and flaming characteristics of wood shingles. Also, a series of fire-tube evaluations of wood treated with creosote oil and pentachlorophenol-oil preservatives emulsified with a solution of sodium calcium borate, showed that the emulsified additive reduced the fire-tube weight loss from 86 percent to 65 percent. This is significant, but it does not compare to a weight loss of only 20 percent for heavy nonpreservative treatments with ammonium phosphate.

Research to determine accurate rates of char penetration for wood showed that the charring rate for Douglas-fir was dependent upon the temperature, density, and moisture content in respective diminishing importance. The rate of char penetration, 1-1/2 inches per hour, was found to be applicable to this species.

g. Environmental effects. Studies designed to establish the effects on wood of widely dissimilar climatic conditions showed an unexpectedly rapid and wide fluctuation in surface temperature. A black-painted board, for example, dropped 30° to 40° F. and recovered its original temperature within 10 minutes when the sun was briefly obscured by a cloud. It seems reasonable to expect that such drastic temperature changes can induce rapid thermal stresses and moisture content changes that in turn can seriously affect the durability of finishes and adhesives. Longwave radiation was found to have an unexpectedly pronounced cooling effect when two boards, one painted black and the other white, were exposed to afternoon sunshine side by side. The black-painted board became much warmer than the other, even though the air temperature was only 10° F. As the sun dropped lower, the white board cooled until it was actually 6° F. below the air temperature, while the black one, although also cooling, remained much warmer than the air. This unexpected development was ascribed to the slightly greater longwave emissivity of white paint. Related effects have been noted since, during both winter and summer. One result is the earlier formation of dew on the white-painted than on the dark-painted surfaces.

Experiments on the effect of exterior exposures on nine different paint systems used on laminated beams showed that white paints were in good condition after 2 years at all sites. A clear polyurethane varnish over a flexible primer was in good condition at three sites, but was in very poor condition at the Harrison site. At all four sites a pigmented water-repellent penetrating stain has worn off rapidly, but could easily be renewed without sanding.

h. Preservative development and treating processes. Research designed to evaluate in-service conditions of preservative-treated products showed that southern pine posts treated with pentachlorophenol in 5 percent solution, zinc meta arsenite, and full-length double-diffusion treated with copper sulphate and sodium arsenate are still giving service after 42 years. Double-diffusion treatments prolonged life of posts three to four times for hardwoods and four to six times for softwoods.

Continued research on effective treatment and conditioning procedures to improve cleanliness of lumber pressure-treated with pentachlorophenol solutions showed that aliphatic solvents were better than higher aromatics in obtaining a clear surface, particularly on ponderosa pine heartwood and Douglas-fir heartwood.

Research on the effectiveness against marine borer attack of combination treatments utilizing waterborne chemicals followed by creosote showed that after 4 year's exposure, double diffusion alone was more effective than creosote alone. A combination of double-diffusion treatment and creosote treatment exhibited no failures in four harbors.

Research at the Institute of Tropical Forestry showed that properly applied non-pressure methods can be highly effective for the treatment of posts for installation in tropical areas. Posts treated by the hot-and-cold bath techniques, using either pentachlorophenol or creosote, should have a service life of at least 15 years. Cold soaking by holding the posts vertically, butt down, in the treating tank is also highly effective. Double-diffusion treated posts, though in service only 3-1/2 years, also show good durability provided the tank method (full-length steeping) rather than the barrel method is used.

i. Sawmill improvement. Studies on the influence of log sawing patterns on subsequent warp and on the strength characteristics of southern pine 2 by 4 studs indicated a controlled sawing pattern can increase the percentage of studs meeting the No. 1 dimension crook specifications by as much as 35 percent.

A comparative sawing performance study of the Duo-Kerf saw and a conventional saw, conducted under commercial sawing conditions, demonstrated that the Duo-Kerf gave a 5.7 percent greater yield. In addition, 80 percent of the boards produced with the Duo-Kerf saw required less planing to produce a smooth surface. An improved design of the Duo-Kerf principle, incorporating the characteristics of the individual chipper and side-dresser teeth into a single tooth, holds promise of overcoming the tendency to deflect in cross-grained wood under production conditions. Improved saw designs, to reduce kerf requirements and improve board surface characteristics, hold possibilities of increasing the potential yield of lumber from a given volume of logs as much as 15 percent.

j. P.L. 480 - India. A study on the working qualities of Indian timbers is located at the Forest Research Institute, Dehra Dun. Experiments on the effect of density upon woodworking properties of Cryptomeria japonica, which is a fast growing species in the lower Darjeeling hills, showed that turning and boring qualities were improved by densifying a piece of the wood in a heated press to a thickness about half the original. Further machining work on the Indian species and the power requirements in the different woodworking operations is in progress. The work was reviewed on the ground by a representative of the U.S. Forest Service.

k. P.L. 480 - Finland. Research on the factors affecting the impregnability of wood showed that penetration of a preservative in both coarse-grained and fine-grained unsoaked test specimens is better with acid solutions than with alkaline ones when initial vacuum is employed. The penetration was poorest with ammoniacal solutions. Further research will be carried on to study the influence of summerwood and the medullary rays on the impregnability of pine sapwood.

l. P.L. 480 - Pakistan. A study on the effect of absorption and penetration of pressure, temperature, and time of treatment of preservatives in tropical timber is underway at the Pakistan Forest Research Laboratory, Sholashahar, Chittagong, East Pakistan. This work was reviewed on the ground by a representative of the U.S. Forest Service.

3. Wood Fiber Products

a. Pulping process investigations. Completion of research on the basic chemical reactions involved in the polysulfide process has demonstrated the technical feasibility of this high-sulfur-content kraft process. The findings are available to the industry as a basis for mill design and industrial application to take advantage of the higher yields of pulp the process offers as compared with conventional kraft pulping.

Further experiments demonstrated that, for best results, the polysulfide liquor must be completely diffused and reactive with the wood before being brought to digestion temperature. This can be done either by using small or thin chips and extending the heating period to maximum cooking temperature, or by a two-step digestion, the first at 120° to 140° C. Either procedure is considered practical for kraft mills. Up to 20 percent more yield of bleached pulp was obtained with 12 percent of polysulfide sulfur on wood in the cooking liquor.

Experiments in the alkaline sulfite pulping of Douglas-fir, in which the liquor was fortified with sodium borohydride, produced large increases in yield of a pulp comparable with kraft pulp in strength. Addition of 0.2 percent of borohydride, based on weight of the wood, increased yield 7 percent; additions of 0.5 and 1.0 percent brought yield gains of 18 and 22 percent, respectively. Alkalinity of the cooking liquor affected borohydride efficiency. Low alkalinity (pH 8 to 9) decomposed the borohydride, while at very high alkalinity (pH 13) the hemicelluloses were dissolved away.

Two-stage sulfite pulping with first an acid sulfite liquor--commonly called bisulfite pulping--and then a neutral liquor appears to offer sulfite mills an opportunity to produce more tear-resistant pulps that have all the other advantages of sulfite pulps, thereby putting them in a better position with respect to kraft mills. An alkaline post delignification treatment of the cooked chips before they are fiberized, but after removal of most of the bisulfite liquor, was shown experimentally to increase tearing resistance substantially. A relatively mild post treatment with 2 to 3 percent of sodium hydroxide for 1 to 2 hours at 130° to 150° C. was used in these experiments. The yield of easily bleachable pulp was midway between those of bisulfite without post delignification and kraft. Tearing resistance was close to that of kraft. The post treatment can be accomplished without any major change in the equipment of existing sulfite mills. The treatment has particular significance for sulfite mills confronted with installation of costly chemical recovery systems. Unless the mills can produce pulp more nearly equal to kraft in tear resistance investment in recovery systems designed to eliminate pollution probably cannot be justified.

Possibilities of a low-cost chemical recovery system for neutral sulfite semichemical mills, now facing high capital investment in recovery plants, are considered bright as a result of experiments with magnesia-base sulfite liquors. While neutral magnesium sulfite is low in solubility, it becomes more soluble in liquors of moderate acidity. A treatment was developed that consists of impregnating mixed hardwood chips with bisulfite liquor followed by neutralization of the liquor to a pH of about 5.5 to 6 by injection of magnesium hydroxide. The resultant pulp was of acceptable strength and stiffness for corrugating medium, the principal product of neutral sulfite semichemical mills. Recovery of chemical is relatively simple and economical.

b. Pulp properties. Research is being conducted on the effects of swelling of fibers with chemical solvents and the resistance of fibers to swelling. One object is to facilitate the study of fiber structure; another is to investigate whether swelling has any effect on fiber bonding, which could have a bearing on paper sheet formation and strength. A water prehydrolysis cook at 170° C. was found to have greatly reduced the resistance of sweetgum kraft fibers to swelling with a cellulose solvent. Prehydrolysis for 60 minutes lowered pentosan content to one-tenth that of the unhydrolyzed pulp, but the cellulose molecules were shortened only about 6 percent. A 150-minute hydrolysis reduced pentosan content only one-half again as much as did the 60-minute hydrolysis, while the cellulose molecules were about one-third shorter than those of the 60-minute pulp. From this it was concluded that swelling resistance was lowered primarily because the cellulose molecules were shortened, since microscopic examination revealed that fibers given the longer prehydrolysis were swollen much more. Even in sweetgum pulps given the longer prehydrolysis, the tertiary layer of the cell wall remained clearly evident under the microscope.

c. Fiber processing. A simple two-stage bleaching process that does not materially affect the high yield obtained with sodium bisulfite pulping gives promise of commercial value in the production of these pulps for papers bright enough to meet book and magazine standards. Bleaching processes commonly used to brighten sulfite pulps involve chlorination, which seriously cuts into the high yields obtainable with bisulfite pulping. A process based on calcium hypochlorite and sodium hydrosulfite, was developed. This treatment produced a satisfactory bleached commercial spruce and hemlock sodium bisulfite pulp of 55 percent yield.

In other research a three-stage process was developed that bleached southern pine kraft pulp to a brightness of 84 to 86 percent without using chlorine dioxide, an expensive bleaching agent. At least 95 percent of the strength of the pulp was retained. The process consists of prehypochlorite stage, an oxidative extraction stage, and a mild oxidative stage. Calcium hypochlorite is used in all three stages with other chemicals. If used alone, it cuts pulp strength and gives the pulp an unstable brightness. Conventional bleaching processes now used on kraft consist of five or six stages to attain the same brightness level. Since each of the five or six stages represents a pollution problem, the simplified three-stage treatment has advantages here also.

d. Papermaking processes. A simple procedure for continuously adding a new starch size to pulp stock was used in studies in cooperation with the Northern Utilization Research and Development Division of the U.S. Department of Agriculture at Peoria, Illinois. The starch, a cationic dialdehyde, was developed at the Peoria laboratories as an outlet for surplus corn. Its electric charge attracts cellulose, hence it is readily added to cellulose fibers in paper without use of other agents commonly required. The starch gives a high degree of wet strength temporarily to paper, making it well suited for toweling and similar products, yet is easily decomposed in alkali, thus facilitating its removal and reuse of the fiber.

Papermaking studies were conducted with a porous sintered nylon press roll located on a smoothing press. This roll permitted higher press pressures and was highly effective in removing water from paper webs. A lightweight sheet was obtained, after passing through this press, with up to 50 percent less water than when using a rubber-covered roll. Paper made with the sintered roll was somewhat more dense; its bursting strength was lower but it was equal to or better in tensile strength and tearing resistance than paper made with the usual rubber roll.

Drying studies of the effect of stretching and restraining wet webs on paper strength show that modulus of elasticity is generally independent of the type of pulp, and it increases with the degree of restraint during drying as well as with the density of the handsheets. Modulus of elasticity in the direction of restraint was found to vary as the cube of density. Tensile strength and strain to failure, on the other hand, were dependent on the type of pulp, as well as on the degree of restraint and density of handsheets. Tensile properties of sheets dried under restraint are retained to a substantial degree by the sheet, even after high humidity exposure or after being soaked in water. Stretching within limits, before drying, improved tensile strength and elastic modulus, but reduced the strain to failure.

Experiments using special chemicals for the separation of printing inks from papers resulted in a satisfactory sheet of newsprint. Printed magazine sections were also treated with this same chemical and the deinked material was used successfully in the manufacture of mediumweight and heavyweight folding boards. Treatments of colored tab cards and colored ledger have resulted in deinked pulps with brightnesses approaching those of pulps commonly used in these grades. This chemical

treatment can be performed at room temperature without steam and caustic soda, which are generally used in many of the commercial deinking processes today. Caustic soda at elevated temperatures darkens papers containing groundwood, such as newspapers.

4. Wood Chemistry

a. Wood carbohydrates and conversion products. Studies of the influence of the special structure of a carbohydrate molecule on its rate of hydrolysis showed that thermal pretreatment of cellulose samples brought about significant improvement in hydrolysis rate and sugar yield. Experiments demonstrated that the nature and location of substituent groups play an equally important role in the further conversion of wood sugars to furan derivatives. Information concerning the basic mechanism of these chemical reactions has practical applications in improving the outlook for the utilization of wood as a chemical raw material.

b. Lignin structure and utilization. The fundamental nature of wood chemistry research was sharply accented with the establishment of a pioneering research unit devoted to the problem of characterizing lignin chemically to create a foundation on which applied research can build. The purpose of this unit will be to elucidate the actual chemical structure of compounds formed in the phloroglucinol and aniline color reaction of lignin. Work will also be conducted on the isolation of lignin in wood without substantial degradation.

Research on the lignin macromolecule obtained from finely ground spruce by cellulytic enzyme action showed that the lignin is degraded acidolysis in aqueous dioxane combined with hydrogenolysis over palladiumcarbon. Also studies of simple model phenol compounds showed that by subjecting them to enzymatic dehydrogenation revealed clues to the nature of lignin linkages. Other work, aimed at converting the lignin in spent sulfate pulping liquors into useful chemicals, showed that by heating the liquors with alkali, 60 to 70 percent of the lignin can be converted to a mixture of guaiacols, catechols, and other phenols potentially valuable for industrial products such as plastics, glues, and pharmaceuticals.

c. Chemistry of wood and bark extractives. The anatomy of some closely related species is so similar that correct identification of the wood is very difficult unless other parts of the tree are available. A chemical test was developed that holds promise for differentiating eastern and western white pine.

Research on pine pollen continued to yield polyphenolic compounds, some of which have apparently not been previously reported in nature. Since only limited research has been reported on pollen polyphenols or on pine pollen, future studies may eventually help to increase the understanding of the biochemical role of these organic compounds in the reproduction of trees.

Pine bark sterols (which are actually triterpenoids) have been characterized and found to consist of a mixture of almost a dozen compounds representing various stages in the biosynthesis and degradation of B-sitosterol, the major sterol. Also a series of chemically interesting and unusual diterpenoids were isolated from jack and sugar pine barks. These include four previously unreported, closely related diterpene alcohols whose novel structures have been elucidated. One of them, 13-epimanool, comprises 6 percent of lodgepole pine bark. Research on lodgepole pine bark has been concluded, with a total of 46 different compounds tentatively identified in the benzene extract. Some 60 different compounds have been isolated so far from the benzene extract of jack pine bark.

Research on naval stores was successful in rapidly separating the nine common resin acids from neutrals without alteration or degradation. Progress was also made in developing a rapid quantitative gas chromatographic method for analyzing complex mixtures of resin and fatty acids.

d. Biochemistry of wood constituents. The production, by fermentation, of the polyhydric alcohols--glycerol, erythritol, and arabitol, was brought about by various species of yeasts which were isolated from natural products. Fermentation conditions were established for each of the organisms, and polyhydric alcohol yields were obtained ranging from 35 to 40 percent by weight of the sugar used. Erythritol and arabitol are now used only as fine chemicals but could be produced at a reasonable price if a demand develops.

Experiments to make a useful product from both the hexose and pentose sugars proved successful when the mold Aspergillus terreus was found to produce itaconic acid (methylene succinic acid), now used to some extent in plastic plasticizers, for both types of sugars. Yields of the acid were about 50 percent from glucose and 40 percent from xylose by weight.

e. Surface and polymer chemistry of wood. Considerable emphasis has been placed on the modification of wood surfaces, by infusion procedures, to improve their finish-holding power. Such treatments, in addition to stabilizing the surface layers, also were found to reduce the rate with which moisture moves to the underlying untreated wood. To obtain such desirable properties by the infusion procedure, resinous material must be properly located in the wood. Research has uncovered considerable information on the influence of molecular size of the resinous material and, also, of the viscosity of the resinous solution on its penetration within the wood.

The bonding of a film or certain resinous materials to wood occurs essentially at the "daylight" surface of wood. This surface has two major components: (1) the exposed, formerly interior, walls of the cell lumina, and (2) the wood substance exposed by the wood cutting operation. The former was created during the growth of the tree and may be tens or hundreds of years old. It may constitute 50 to 90 percent of the daylight surface. The latter is the fresh surface created by the plane or saw. It may constitute 10 to 50 percent of the daylight surface. Because it may be only seconds, minutes, or days old, its reactivity toward certain resinous materials is many times greater than that of the lumen walls.

f. Process development. Experiments performed on delignification of wood with solutions of equivalent acidity demonstrated that the solid residue yield is approximately determined only by the amount of lignin put into solution, even in such widely different systems as those containing sodium xylenesulfonate, sulfolane, and dioxane. The residues produced have the appearance of a high-quality cellulosic material that would be well suited for further processing.

g. Analytical development, instrumentation, and service. Because of its greater speed and sensitivity over paper chromatography, thin-layer chromatography has found wide application as a qualitative tool on the separation and identification of lignin intermediates. extractives, flavonoids, and tall oil constituents. The necessary equipment and techniques were developed to establish the procedure on a quantitative analytical basis. These procedures were shown to have the accuracy, the simplicity, and the versatility to handle problems amenable to the thin-layer process.

h. P.L. 480 - Finland. A project on the aerobic bacterial degradation of lignin is currently being carried on at the University of Helsinki. The objectives of the project are to obtain information on the types of soil bacteria involved in the degradation of lignin, to identify these organisms, to study their nutritional requirements, and to determine the kinds of transformations of the lignin molecule they are able to effect. Isolates have been made from forest soil by the use of a lignin medium. Over 900 isolates have been obtained, and one of these isolates proved to be a yeast. This is the first time that a yeast has been implicated in lignin degradation.

Research on the accessibility of cellulose fiber resulted in the development of a new method for determination of iron in cellulose based upon x-ray fluorescence. Also two new experimental techniques were developed for verification of the presence of minute amounts of acid which remain attached to cellulose fiber. These findings are included in Dr. Ant-Wuorinen's four publications relating to various aspects of cellulose fine structure. All of the work performed thus far has added measurably to an understanding of the physical and chemical behavior of wood.

5. Wood Engineering

a. Fundamental wood properties. Green wood of Hawaii-grown Nepal alder (Alnus nepalensis) was found to be generally comparable to wood of the same species grown in India. The wood is appreciably below red alder, a western U.S. species, in specific gravity, shrinkage, and flexure, but comparable with it in hardness. Research on this species is part of a survey of Hawaiian woods designed to evaluate them for furniture and cabinet use.

A study of what happens to wood when it is loaded beyond its proportional limit has provided a means of describing its rheologic behavior in terms of the creep function of linear viscoelastic theory. Elastic compliance appeared to have the same magnitude in tension and compression. Flow compliance, however, was twice as great in compression as in tension at any given time during the loading cycle. A linear relationship appears to exist between strain and stress up to at least 60 percent of the ultimate static strength.

Continued research on wood treated with fire-retardant chemicals showed that fire retardant salts differ markedly in their effects on wood properties. The immediate effect on strength appears to be related to the physical presence of the chemical in the wood, the hygroscopicity of the chemical, and the degree to which the chemicals penetrate the cell walls of the wood. Individual chemicals differ considerably in all of these factors and thus produce widely different immediate effects on strength, moisture content, and swelling characteristics. Loss of strength in aging was accelerated by an acid salt but not by an alkaline salt. The aging effect is apparently related to the extent and nature of chemical degradation produced by the chemical solution.

A computer-programmed analysis of extensive stress data obtained on red oak boards during the early stages of drying has made it possible to assign definite stress values to various parts of a board being dried, rather than the crude relative values previously available. The analysis is continuing on data for the later stages of drying, and procedures are being considered for relating the stress values obtained to strength properties. Purpose of this work is to make it possible to determine temperature and humidity conditions that achieve drying at the fastest practical rate without developing stresses great enough to cause serious drying degrade, such as honeycomb, collapse, and splitting. A similar analysis was made

of stress data obtained in a study of temperature and moisture content effects on the perpendicular-to-grain mechanical properties of pondersoa pine. Modulus of elasticity was found to be about the same in both tension and compression for comparable temperature and moisture content conditions; it was much lower in specimens with growth rings at 45° to the loaded surface than in those at 0° (flat grained), and highest at 90° (vertical grained). Maximum tensile stress, on the other hand, was highest in specimens with rings at 90°, intermediate at 45°, and lowest at 0°. Deformation to failure was three or four times as great in specimens with rings at 45° than in those with rings at either 0° or 90°, probably because shearing strain was greater.

Methods and techniques for nondestructive testing of wood to determine its strength and related properties without damaging it were examined at a symposium held at FPL in cooperation with the National Lumber Manufacturers Association. Some 100 representatives of industry, universities, and other research institutions heard specialists in various branches of the subject. A recommendation was adopted that representatives of all branches of the wood industry meet in 1964 at the Forest Products Laboratory to define more clearly the needs for nondestructive test methods.

Nondestructive vibration tests of clear Douglas-fir specimens 2-by 2-by 40-inches in size indicated that either dynamic or static modulus of elasticity can be used to estimate modulus of rupture in flexure and maximum crushing strength parallel to grain. Shear and toughness did not correlate well with vibrational characteristics. Experiments with air-dry white fir 2 by 4's of No. 2 Common grade and redwood 3 by 8's of very low quality indicated that even large numbers of such strength-reducing characteristics as knots do not interfere seriously with estimates of modulus of rupture from either static or dynamic modulus of elasticity as determined by vibrational characteristics. Correlation of modulus of rupture with specific gravity was poor, however, especially for the redwood beams.

b. Analytical mechanics. The basic importance of developing new and more refined engineering theories concerning wood as a structural material was recognized with the establishment of a pioneering research unit in analytical mechanics at the Laboratory.

Research in this unit is concerned with theoretical considerations and use of analytical mechanics techniques for interpreting experimental data. One study, for example, involves the behavior of wood under stress to develop a better understanding of the mechanism of failure. Ultimately, it is hoped to establish more efficient design criteria for engineers charged with the planning of structures.

An analysis of radial tension stresses in curved laminated beams, the occurrence of which is not well understood, was made using the theory of orthotropic elasticity. The immediate object was to check on the stress values obtained by a more elementary method long in general use, but about which some doubts have been raised by practical experience. While generally confirming the older theory, the new analytical approach indicated that radial tensile strength is reduced when a bending stress is present--as is generally the case in use of such beams.

c. Design criteria. Design criteria developed generally for plywood shell structures under combined loading conditions proved useful in designing a nose fairing for the Polaris A-3 missile, now in successful use by the Navy as a weapon launched from submerged submarines. The work was done in cooperation with the Office of Naval Research. Plywood was chosen because of its low weight for its stiffness and strength, and because of its marked superiority to high-strength metals and plastics

in resistance to crack propagation. The nose fairing is approximately 6-feet long by 5 feet in diameter at the large end and 2 feet at the small end. It has been established as standard for this missile; several successful launchings have proved out the design.

Research to increase the load-bearing capacity of laminated beams by prestressing them with steel cable, as described last year, continued to yield promising results. When beams fabricated of relatively low-grade lumber were prestressed with cable, bending strength was increased by about 30 percent. Moreover, variability between beams was reduced by one half.

The potential inherent in sandwich construction was illustrated when the Forest Products Laboratory collaborated with a West Coast aircraft builder to show how paper and plywood could be combined to build a radically different type of fire lookout tower for use in forests. Models of two designs, one with a cylindrical center column and the other one of triangular shape, were built. The inherent light weight and great stiffness and strength of sandwich construction open new possibilities for erection of such towers at points inaccessible for conventionally built ones. The sandwich construction used consisted of honeycomb cores of paper, resin treated for water resistance and faced with plywood.

d. Structural utilization. A study of temperatures occurring in various parts of wood houses in several areas of the United States found that maximum temperatures in walls may occasionally exceed 130° F. for short periods and the roof temperatures may briefly exceed 160° F. The experimental data were summarized to show cumulative duration of temperatures at various levels to define, in the most useful manner, the environment under which materials or adhesive systems will be required to function. These data are useful in selection of proper materials for permanent structures.

The possibility of the industry adopting new size standards for dimension lumber and the use of new sizes in joist and rafter span tables has raised a number of questions about the shrinkage and stiffness in such lumber. Research on several species and grades indicates that the stiffness remains about constant as the lumber dries. The effect of reduced size brought about by shrinkage is balanced by the increase in modulus of elasticity resulting from the lower moisture content.

e. Packaging. Research on the use of adhesives instead of nails for boxes has shown that less material per box, hence better utilization of material, can be realized, provided the adhesives perform properly. A new container material called Fiberneer, resembling single-wall corrugated container board but consisting of paper-overlaid veneer facings on both sides of the corrugated sheet, was developed and shows high promise as a lightweight, moisture-resistant container board with excellent stacking strength. Extensible kraft paper was used for the overlays. Pilot-plant experiments at commercial board mills indicate it can be made on high-speed machinery and scored for future folding into boxes. Fiberneer's top-to-bottom compressive strength approaches that of the best triple-wall material, yet it is lighter and only one-half as thick. This work is being done in cooperation with the Air Force.

Research on double-wall fiberboard containers has resulted in a recommendation that present freight classification load limits for this type of container be increased. Specifically, the petition recommends that Rule 41 of the Uniform Freight Classification be modified to permit gross weight limits of 225 pounds instead of 140 pounds for containers made of 500-pound-test double-wall and of 250 instead of 160

pounds for those of 600-pound-test double-wall. Also, experiments of chemical treatments, designed to improve the moisture resistance of corrugated fiberboard and thereby prevent loss of compressive strength in containers exposed to high humidity indicate that substantial improvement in compressive strength can be attained. The best treatment resulted in containers almost as strong under compressive load when exposed to moist conditions as untreated containers exposed to a relatively dry condition.

f. P.L. 480 - Finland. Research at the State Institute for Technical Research, Helsinki, on the effects of temperature, moisture content, and heating time on the strength properties perpendicular to grain for three Finnish species shows that the maximum tension strength values are smaller for pine than for birch. Modulus of elasticity and compression strength, however, are about the same for the two species. It was found that the effect of specific gravity is smallest at higher moisture content values. Also the rise in temperature weakens wood more at higher than at lower moisture content values.

6. Regional Utilization Problems

The details of actions and accomplishments by regional Forest Experiment Station forest utilization research programs during the past year can be only touched upon here. A few are given as illustrations:

a. Regional problem analyses. Analysis of utilization needs and opportunities in the Pacific Northwest indicate that there is no generally accepted concept of wood quality in the forest industries or in forest research and no coherent conception of quality as a forest management device. It is suggested that all quality evaluation and control systems can be harmonized when quality is treated as a systematic means of establishing the suitability of wood or timber for a particular purpose. Otherwise, it is difficult to translate value judgments from one quality system to another interdependent one in an integrated enterprise.

In the Central States the most important trend in the primary wood-using industries, especially the sawmilling industry, is the gradual transition from the small, low-capital investment, low-production type of operations to larger, more complex, more heavily mechanized operations which are capable of the production necessary to carry the cost of their changed physical and financial characteristics. Efficient operators appear to have accepted the lower profits situation and are making capital investments in new machines and equipment in order to make their operations more profitable. Loggers are trying new equipment such as rubber-tired skidders and truck self-loaders of the hydraulic boom, or dip-stick type. Markets for the lower grades of hardwood logs and lumber generally have remained quite strong throughout the year due to the strong demand for pallet and crate materials. In some areas a definite trend can be seen toward breaking down rough lumber into semifinished products before marketing. Thus, transportation costs are reduced by increasing the percentage of usable material in a shipment.

b. Solving regional problems. In the Pacific Northwest a widespread analysis of compression failures in blowdown salvage timber resulted from the greatly increased occurrences of this defect in lumber and poles after the 1962 Columbus Day windstorm. Compression failure was found to be a significant degrading factor in timber from some blowdown areas, but not as serious as originally feared. It does not show a pattern with respect to species or site, but appears to be related to size of tree. Poles and structural timbers are the most seriously affected products. Careful grading and inspection seem to have prevented customer complaints.

Full-time and intermittent sprinkling with water gave good protection to red oak, sweetgum, hackberry, and cottonwood in a study conducted by the Southern Forest Experiment Station. All spray treatments provided better storage conditions than no treatment. At the end of 16 weeks, sprinkled logs were practically free of stain. To estimate the dollar loss from stain during a year of storage, the logs were sawed and the lumber was graded with and without stain as defect. The comparison showed surprisingly small differences among spray treatments, with the average loss in value during storage being about 5 percent. Among the species, hackberry suffered most, losing 14.3 percent. The other species lost only 0.3 to 1.9 percent during the whole year. No insect damage was observed.

c. Assisting extension and action agencies. The application of research results necessarily must be brought about in many different ways. Station FUR work program emphasizes maximum assistance to the established public extension and action agencies to do this.

Assistance to extension agencies has involved primarily technical advice and guidance and the training of extension workers. Points of contact are the State Extension Services, the Forest Service Regional Divisions of State and Private Forestry, and the Cooperative Forest Management staffs of the State Foresters. With the assistance of the FPL, backstopping and training has continued actively for these groups.

Help to action agencies has been concentrated mainly on the Rural Area Development (RAD) activities of USDA, especially in connection with projects referred by the Area Redevelopment Agency (ARA) of the Department of Commerce. All Stations have assisted in RAD basic planning and on the details of development programs, pilot economic studies, and investigations and recommendations on specific proposals. Activities vary widely in relation to technical knowledge and experience available from local sources and other agencies. For example, the Pacific Northwest Station gave technical advice on the following ARA loan proposals:

(1) Hardwood pulp marketing study involving logging, manufacturing, and marketing problems of utilization of Northwest hardwoods. (2) Feasibility study for a particle board plant in Ferry County, Washington, using Douglas-fir and western larch. (3) Feasibility of a log-sorting and handling station near Randle, Washington. (4) Establishment of a charcoal plant in Republic, Washington, using sawmill residues. (5) Establishment of a logging operation in the vicinity of Wrangell, Alaska. (6) Establishment of an alder sawmill at Forks, Washington. (7) Construction of a plywood plant in Ferry County, Washington. (8) Economic feasibility of utilizing logging residues in selected Washington counties. (9) Feasibility study for an integrated wood products industry in or near Ferry County, Washington.

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B. FOREST ENGINEERING RESEARCH

Problem

Multiple use requirements dictate that highly efficient engineering systems be developed to permit protection and maximum utilization of our forest resources under proper management practices. Past research in this field has been largely confined to projects with relatively limited objectives in contrast to the need for coordinated systems required by multiple use considerations. National forest lands especially pose a challenging problem in utilization and protection due to their relative inaccessibility and land management objectives.

One of the most important forest activities is the harvesting of the timber--a major materials handling and transportation job. Reduction of costs in this activity will be of significant assistance to the timber industry and aid in improving management of forest lands. Harvesting is made increasingly difficult and costly due to the restraints imposed by multiple use requirements. These requirements add to logging costs to provide for proper protection of watershed, landscape, and recreation values. Vastly improved transport and harvesting methods are needed to reduce raw material costs while protecting other resource values.

Harvesting today can be as much as 70 percent of the cost of producing and delivering wood to the primary processing plant. In the case of a pulp plant, the cost of wood at the plant represents 60 percent of the cost of producing unbleached kraft pulp. In other basic industries cost of raw materials in proportion to total production costs runs significantly lower. (For example, in plastics it is only 10 to 30 percent.)

Mechanization, comparable to that achieved in American agriculture is sorely needed. The output per unit of labor in agriculture is nearly double that for forest industries.

Results of a recent study indicate that in Oregon and Washington alone there are at least 28 billion board feet of timber, characterized by low volumes per acre, steep growing terrain and costly road access, which will require special harvesting and removal techniques.

In Alaska there are an estimated 61 billion board feet of timber which cannot be successfully logged with the conventional systems that are costly to the operators and damaging to soil, water, and aesthetic values.

Heavy residues of current and past logging in heavy timber stands of the West Coast are wasteful of materials, create an explosive fire hazard, and interfere with reestablishment of the timber resource.

Logging systems and equipment for economical timber harvesting and cultural operations on small woodland ownerships are nearly nonexistent. Specialized equipment is urgently needed.

In eastern hardwoods some 74 percent of the total volume is considered low grade and culls, requiring vastly cheaper harvesting methods so they can be removed economically and the sites replanted to improved species.

Sharply reduced nursery and planting costs are needed to accelerate the job of replanting 52 million acres of commercial forest land--about 11 percent of all commercial forest land.

USDA and Cooperative Programs

The possibilities of engineering research in multiple use forestry operations are being expanded almost daily by the rapid development of new materials and methods of construction, new chemicals, new forms of transport, new forms of energy, and new devices for automatic control. We are experiencing a tremendous explosion in technology and the need now in forestry is to perfect the engineering systems to take advantage of these advances.

Four major problem areas involved in multiple use forestry have been identified and engineering laboratories are now established in the geographical area in which each problem is dominant. Most problems are now confined to a single geographic area, consequently, each laboratory has national, or at least interregional, responsibility for its assigned mission. The research is primarily applied.

Research in each problem area is guided by engineering systems analyses. Work, at present, is concentrated largely on one of the most important of forest engineering activities--materials handling and transportation of forest products. One of the first steps is the identification of objectives--a prescription for the job to be done--wherein goals, parameters, and criteria for attainment of the engineering system or process are defined. The final step is the development of specifications for new equipment, new methods, and new concepts of process organization.

The translation of multiple use land management requirements and operations into engineering terms and "systems of operations" is a pioneering attempt in both engineering and forestry which requires new approaches and concepts, and much imagination and inventiveness. In this approach we are attempting not only to improve the efficiency and lower the costs of harvesting but to design systems which will improve and enhance other multiple use activities as well.

Once the specifications are drawn, a review and appraisal are made of any and all items of existing equipment believed capable of meeting requirements. If existing equipment does not meet the specifications, steps are taken to obtain modifications or to develop prototype new equipment. To the extent possible, private industry is encouraged to do this work, either independently or by contract. The prototype or modified equipment is then tested against the specifications.

Close liaison is maintained with other agencies, both domestic and foreign, engaged in forestry and equipment development and with equipment manufacturing industries, as well as with defense laboratories, to determine whether presently developed equipment, processes, or techniques can be advantageously applied in forestry operations. The program is directed particularly to original applications designed to revolutionize forest production, protection, and utilization while considering other multiple use requirements.

Laboratories have been established by assignment of project leaders at Auburn, Alabama (Auburn University); at Houghton, Michigan (Michigan Technological University); at Bozeman, Montana (Montana State College); and at Seattle, Washington (University of Washington). Each is closely associated with the engineering college or school where mutually profitable cooperative research programs are underway.

An engineering analysis to guide a research program in the Appalachian forestry complex has been started. It is expected that field activation will begin in the fall of 1964 with establishment of a project at Morgantown, West Virginia (University of West Virginia).

The objective of the work at each laboratory is to improve the efficiency and economy of forestry systems in its assigned problem area. (Included in the systems are methods of harvesting and transportation, reestablishment of forests, timber stand and watershed protection and improvement, and providing means of access for all multiple use purposes.) The assigned problem areas are:

Bozeman, Montana--Relatively small-sized timber on steep slopes and erosible soils.

Houghton, Michigan--Deteriorated northern hardwood stands located, generally, in rolling terrain.

Auburn, Alabama--Intensively managed timber stands and component forestry operations in seed production and nursery operations.

Seattle, Washington--Virgin timber stands and utilization of heavy residues characterized by West Coast and Alaska forests.

The Federal scientific effort devoted to research in this area totals nine professional man-years.

Progress--USDA and Cooperative Programs

The engineering research program of the Forest Service represents a new approach to improving the efficiency and performance of forestry operations wherein entire systems are analyzed to identify technical problem areas, criteria, parameters, and best opportunities for payoff on research investments and efforts. Early work has concentrated on studies contributing to basic understanding and knowledge of critical elements of forestry materials handling operations. A few of interest are:

1. Pipeline Transportation

Earlier studies have shown transport of large volumes of wood chips in water pipelines to be feasible, hydraulically. Simulation of operational conditions by means of a mathematical model has shown that the economics of pipeline transport cannot be determined until more basic engineering data are available to provide criteria on: (a) friction losses, (b) limits of chip concentration, (c) pumping costs, and (d) requirements of chip input systems. Design of a test system to provide the required information is underway.

2. Chipping in the Woods

Further analysis of the chipping in the woods system has shown that its potential cannot be fully realized until more reliable scientific data are available on the chip-producing process itself and on the physical and mechanical handling properties of the chips themselves. Studies are planned to obtain these data.

3. Logging Road Cost Reduction

Analysis of the potential benefits of using wide-tread single tires in place of conventional duals on logging trucks indicates that road construction costs and upkeep may be reduced significantly. Design of a test section of road to be constructed and operated in cooperation with Weyerhaeuser Timber Company has been completed. Effects of single versus dual tire operation on several road base designs will be evaluated.

4. Balloon Logging

The first phase of a systems analysis on the concept of using a balloon to support one end of a log in a high-lead logging operation indicates technical feasibility. The second phase of the analysis dealing with economic feasibility is now underway. Use of the concept would permit a significant decrease in road construction; reduce rig-up time and dependence on yield per acre; limit soil disturbance; permit yarding uphill, downhill, or sidehill; facilitate shoreline operations such as in Alaska; and reduce yarding costs on difficult terrain. Balloon logging appears to offer many of the advantages hoped for in helicopter logging--but at much less cost and risk and without need to wait for technical development and availability of suitable helicopters.

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V. FOREST ECONOMICS AND MARKETING RESEARCH

A. FOREST SURVEY

Problem

Up-to-date information on the Nation's forest land and timber resources and prospects for future timber supplies and demands is essential to guide policies and programs of forestry agencies, business decisions of forest industries, and rural development programs. Such information on the area and condition of forest lands by various classes of ownership; the volume, quality and location of standing timber; trends in timber growth and mortality; and present and prospective amounts and kinds of timber cut for industrial products is provided only by the Forest Survey. Because of rapid changes in timber resources resulting from growth, industrial cutting, and changes in land use, there is increasing need for periodic analyses of the timber situation for all forested States and for the Nation as a whole.

USDA and Cooperative Programs

This continuing long-range program of applied research is conducted primarily through the field Experiment Stations of the Forest Service in close cooperation with State forestry agencies, wood-using industries and other cooperators who contribute manpower and funds. Essentially all of the 775 million acres of forest land in the United States has been inventoried at least once. Resurveys to provide up-to-date information and to determine trends in timber supplies, forestry problems and forest industrial development opportunities are being made in all States at intervals of from 8 to 15 years. Improved inventory and growth projection techniques also are being developed by a continuing program of mensurational research.

Research on timber resource surveys and appraisals involves about 66 man-years of Federal professional effort annually.

Program of State Experiment Stations

No report.

Progress--USDA and Cooperative Programs

a. Field inventories. During recent years the nationwide Forest Survey has been completing inventories in various States on an average cycle of about 11 years, compared with an average resurvey goal of about 9 years. During the past year field surveys have been conducted primarily in Alaska, Oregon, Washington, California, Arizona, Kentucky, Pennsylvania, Maryland, North Carolina, Alabama, and Louisiana.

b. New Hampshire's forest land increasing. A recent resurvey of New Hampshire showed many changes since the initial Forest Survey in 1946-48. The area of commercial forest land increased 5 percent, largely as a result of abandonment of farmland. No county in the State now has less than 80 percent of its land area in forests. Although the growth and cut of sawtimber have been approximately in balance, total timber volumes have continued to increase. Lumber has continued

to be the leading timber product, with pulpwood amounting to about one-half as much as the lumber output.

c. Timber resources increasing in Georgia. The third Forest Survey of Georgia has revealed an increase of 4.5 million acres, or 21 percent, in the area of commercial forest land during the past 25 years. Much of this increase occurred on the Piedmont where large areas of former cropland have reverted to forest as a result of planting and natural reseeding of pine. Since 1936 the volume of softwood growing stock has increased 19 percent and softwood sawtimber 26 percent. In recent years growth of softwoods has exceeded the cut. Growth of hardwood growing stock, on the other hand, barely replaced the cut while hardwood sawtimber growth was less than the cut. Inventories of trees suitable for gum naval stores showed that the number of slash and longleaf pine available for gum production is at least 3-1/2 times the number being worked.

d. Eastern Oregon resurvey completed. A new report for eastern Oregon describes the timber resources of that area and points out industry supply problems and timber production opportunities. This study also evaluates possible solutions to the problem of converting old-growth forests to rapidly growing young stands capable of providing a continuous flow of desired timber products. Eastern Oregon contains 11.5 million acres of commercial forest land with a total volume of 125.5 billion board feet of sawtimber. Over 90 percent of the timber cut goes into one product--lumber. Future growth and development of the forest economy of eastern Oregon will depend to a great extent upon full utilization of the forest through product diversification, remanufacture of lumber, and development of wood-using industries based on plant residues. Conversion of 1 million board feet of standing timber to logs, for example, now provides 2.7 man-years of employment in eastern Oregon; the same volume converted to rough dry lumber provides 7.0 man-years, production of millwork provides 15.4 man years, while production of plywood furnishes 15.8 man-years of employment. Currently an average of about 8.5 man-years of employment are provided in eastern Oregon for each million feet of timber harvested, compared with 20 man-years in western Washington.

e. First Wyoming inventory completed. The first complete inventory of Wyoming's forest indicates a present timber volume of 22.6 billion board feet on 4.9 million acres of commercial forest. Sawtimber stands, largely overmature, occupy three-fifths of the commercial forest area. Timber products output has been increasing but there are opportunities for greatly increasing the cut. Other forest values--water, recreation and grazing--must be considered along with timber in the management of Wyoming's forest area.

f. Pole production decreasing in Inland Empire. The latest survey of commercial pole production in Idaho, Montana and northeastern Washington, made as part of the determination of drain on the commercial forests, showed a reduction of nearly 29 percent between 1960 and 1962. Current production is now substantially below output in the peak year of 1947.

g. Pulpwood production continues to increase. Pulpwood production in the Lake States reached 3.3 million cords in 1962, a 6 percent increase over 1961. Michigan was the leading producer in the Lake States followed closely by Wisconsin. Aspen is now the leading pulpwood species in the area, followed by spruce and balsam fir.

In the South pulpwood production increased 6 percent between 1961 and 1962 to an all-time high of 25.6 million cords. Gains varied from 47 percent in Oklahoma to 1 percent in North Carolina. Georgia was the leading producer with 5.2 million cords while Alabama ranked second with 3.4 million cords. Since 1956 the volume of pulpwood trucked from stump to mill has increased 70 percent, while rail and barge shipments increased only 1 percent. Much of the pulpwood produced in the South is now transferred from truck to rail cars at mechanized wood yards.

h. Inventory methods improved. Improvement of procedures for supplemental photo interpretation of major land-use classes has provided a means of increasing efficiency in estimation of forest land area and timber volumes. Data from seven Washington counties, for example, showed that a combination of field and photo surveys were from 6 to 15 times more efficient in estimating commercial forest land than surveys based on field plots alone.

i. Public Law 480 projects. During the past year final reports have been issued for two of the three projects authorized under Public Law 480. The first report, Increment Forecast Methods for a Large Forest Area, presents an excellent review and evaluation of past work followed by a number of worthwhile proposals for improvement of procedures now available. The second report, Improved Forest Survey Methods, presents an evaluation of a number of techniques that have important applications to the Forest Survey projects in this country.

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B. FOREST ECONOMICS

Problem

Developing and managing the forest resources on 770 million acres of forest lands in the United States involves many alternatives and questions concerning investment opportunities, costs and benefits. These concern some 4-1/2 million landowners and many industrial and public land managers. Outlays for development, protection, and production of timber, water, recreational services, wildlife and forage now exceed $400 million annually on forest lands and are increasing each year. Installed forest assets, including land, growing stock and improvements, have a capital value of at least $25 billion. The problem of developing and managing this enormous capital resource, moreover, is becoming increasingly complicated by growing conflicts between alternative uses of forest land.

Administrators of public forest land require economic criteria and guides to efficiently allocate public funds among alternative forest practices, producing units, and development opportunities. Guides also are especially needed for integrating multiple uses of forest land for greatest public benefit. Managers of industrial forests must develop management plans based on cost and return determinations. Production and investment decisions of 4-1/2 million farmers, businessmen, professional people and other owners of forest land and timber resources are also influenced by economic considerations. Thus economic analyses are needed to guide forest policies and programs, to evaluate institutional arrangements for forest ownership and conservation, and to assure optimum allocation of available funds for improving supplies of forest products and services.

USDA and Cooperative Programs

The Department conducts a continuing long-term program of applied forest economics research through the regional experiment stations of the Forest Service. Close coordination of forest economics research with timber management research is essential in studying problems of timber growing; with forest fire, disease, and insect research in appraising problems of forest protection; and with watershed, range and recreation research in evaluation of competing and multiple uses of forest lands. Cooperation is also maintained with the Economics Research Service, State Agricultural Experiment Stations and Forestry Schools to coordinate related programs. Forest Service effort devoted to research in this field totals 28 professional man-years annually.

Program of State Experiment Stations

Much less comprehensive research has been conducted in the economics of production than in marketing. Physical data developed has limited usefulness until it has been subjected to rigorous analysis for economic feasibility, and a beginning in this direction has been made. One important hypothesis being given some consideration is that a farm forest management program can be included in a farming system with little increase in cost since it could make for a better utilization

of farm labor. Input-output data are being obtained including the cost of cull tree removal. Some work has been done in land resource use in an attempt to determine how well the production of forest products can compete with other enterprises. A limited amount of work has been done on the effect of taxes on sound forest management, and some thought has been given to the problem of land values and opportunities for multiple use, but valid recommendations can hardly be drawn from information thus far.

A total of 1.3 professional man-years has been devoted to this broad area of work.

Progress--USDA and Cooperative Programs

a. Timber supply outlook in the Douglas-fir region. The long-run timber growing potential of western Washington and western Oregon based on economic criteria has been estimated at 13.2 billion board feet annually, or about 20 percent greater than the average annual harvest of 11 billion board feet during the 1950's. This estimate takes into account assumed changes in land use and shifts in ownership of commercial forest land and, particularly, the prospective responses of six classes of owners to economic factors influencing the business of timber growing.

With present trends in forest management and timber utilization in the Douglas-fir region, it will take more than a century to harvest all timber older than the economic rotation ages developed in this study. Although projected harvests decline in the next two decades, the study indicates that with development of roads and intensification of management the annual harvest could remain above the level of the 1950's and eventually increase to the long-term potential of approximately 13 billion board feet.

b. Evaluation of white pine weevil control in the Northeast. White pine weevil attacks in the Northeast have been causing an estimated $7 million of damage annually in white pine timber stands. Studies of investment opportunities in white pine weevil control indicate prospective rates of return on public funds ranging from 3.3 to 8.1 percent under various management circumstances--for example, when treated stands are less than 20 years old, 75 percent stocked with pine and experiencing 1-3 weevil attacks per log in crop trees. For private timber growers rates of return are estimated at 2.2 to 7.0 percent, depending upon local factors.

c. Reforestation in the Pacific Northwest. Approximately 5 percent of the commercial forest land in Washington and Oregon, or 2 million acres, is not stocked with forest trees. In addition to the task of restocking this large area, the current reforestation job includes regenerating annually some 255,000 acres of newly burned and clear-cut land. The current level of artificial reforestation is about 200,000 acres a year, about half planting and half seeding. Annual investments in reforestation on public and private lands have increased almost 10 times from $800,000 in 1949 to $7,500,000 in 1962. In the same period average costs per acre increased 40 percent from $26.07 to $37.37. Further increases in costs have been avoided by increasing the proportion of less costly seeding in lieu of planting small trees.

d. Computer program for rate-of-return calculations. An electronic computer program has been developed for calculating rates of return for complex forest-investment alternatives. This program will evaluate six investment alternatives simultaneously and perform the analyses repetitively for many cost and price situations. It permits evaluation of rotations up to 99 years with up to 50 yields of each of three forest products. Provision is made for 40 periodic costs, 10 levels of fixed annual cost, 10 rates of change in fixed costs, 20 price

combinations, and 25 land values. To facilitate use of this program the Southern Forest Experiment Station will provide, upon request, a duplicate deck of FORTRAN cards plus a written program for an IBM 750 111. It is also possible to use other computers of the IBM 700/7000 series and certain other manufacturer's models with little or no modification.

e. Investments in white and red pine release in the Lake States. Appraisals of the response of white and red pine to release from aspen and birch over-story competition indicate a wide range in profitability for such treatments, varying from net losses to more than 12 percent return on investments. Investment opportunities in releasing white and red pine from competing hardwoods need to be evaluated in relation to species, site quality, market areas, stand age and density, degree of release.

f. The small woodland owner in the Missouri Ozarks. In the eastern Missouri Ozarks business and professional people own 39 percent of the nonindustrial private forest land, retired people 31 percent, and farmers 20 percent. Together they constitute 70 percent of the woodland owners. The average owner is over 50 years old, owns about 500 acres of woodland and lives in the country where his woodland is located. Owners, for the most part, purchased their woodlands and have held them on the average for about 16 years. Only 2 percent of the woodlands were valued at more than $20 per acre. Nearly three-fourths of the woodland area was estimated to be worth $10 or less per acre due to the deteriorated condition of the timber stands.

g. Characteristics and motivations of forest landowners in Ohio. Data from 160 forest owners interviewed with respect to their response to 17 woodland management practices indicated that owners most likely to adopt one or more of these practices were characteristicly innovators, participants in the ACP program for woodland practices, educated through or beyond high school, and owners of more than 100 acres of woodland. While relationships between forestry efforts and other characteristics were less definitive, owners most apt to adopt woodland practices were also under 50 years of age, received gross incomes of $10,000 or more, or received over $1.00 per acre per year income from woodlands in the past five years. While profits appeared to be the principal objective of woodland owners, they were hampered in achieving this objective by lack of technical knowledge, more rewarding alternatives and lack of time for forestry activities.

h. Pest control in ponderosa pine. Economic analyses of management alternatives in young ponderosa pine stands in the Pacific Northwest indicates that dwarf-mistletoe control is a more remunerative public investment than precommercial thinning. Another exploratory study indicated that escape of European pine shoot moth into the ponderosa pine region from its present area of containment in western Washington and British Columbia could cause a long-run reduction in stumpage receipts estimated at between $7 million and $39 million annually.

i. Multiple-use contributions in Utah. A pilot study near completion in the Paunsauqunt Plateau area of Utah revealed that in some cases economic contributions of the range-livestock industry, in terms of both primary values plus values added, are exceeded by other wild land uses for wildlife, timber, water, and particularly recreation.

j. Computer mapping system for forest properties. A computer mapping system has been developed for forest properties in which up to 99 different forest cover and land characteristics can be coded on E.D.P. cards. The program will print out

maps showing location of individual or combinations of forest characteristics, and corresponding tables of acreages.

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C. FOREST PRODUCTS MARKETING

Problem

Recent trends in national consumption of lumber and certain other wood products, together with increasing growth of timber, point up the need for expanded markets to use available wood supplies. Also, there is much unemployment and need for economic development in many areas where the bulk of the Nation's timber resource is located. Full contribution of this resource to the Nation's economy can be realized only through finding ways of improving markets for all kinds of available timber crops. To achieve this goal will require research to identify and evaluate factors that influence consumption of lumber and other materials for various end uses such as construction, shipping and manufacture, and to determine what action is needed to expand wood markets. There is also need to improve the efficiency of marketing systems and practices to increase the competitive strength of wood products, and to develop new arrangements to overcome the difficulties of small-scale operations in timber production, processing, and distribution. Strengthened research on trends in wood consumption will also aid in appraising future markets and prospective resource problems, and thereby guide forest policies and programs aimed at keeping the Nation's timber budget in balance.

USDA and Cooperative Programs

This is a continuing program of applied research conducted in part by regional experiment stations and in part by the Washington Staff. Close cooperation is maintained with other scientists, particularly in forest products and engineering research and in cooperating industries. Cooperation also is maintained with the Statistical Reporting Service, State Agricultural Experiment Stations, forestry schools, and forest products trade associations. Forest owners, loggers, and producers and various users of wood products cooperate by supplying production and marketing data.

Federal effort in this area of research totals 34 professional man-years annually.

Program of State Experiment Stations

The large number of tree species, differing in important wood characteristics, and the many purposes for which forestry products are used, necessitate buyers for many types of products. There are not only markets for various kinds of lumber but for many other products such as wood pulp, veneer, plywood, cooperage, poles, posts, piling, etc. Despite the complexity and importance of the market, there was little comprehensive information available relative to the characteristics and structure of the market prior to the initiation of regional research. Of the 39 Hatch marketing projects underway in 1963, 25 were concerned with market structure, practices, forces, and performance. Most of these studies have been contributors to regional projects NEM-24, NCM-27, and WM-42. Eight studies were classified under prices--supply, demand, and utilization; two under costs, margins, and efficiency of operations; and two were concerned with transportation and inter-market competition.

The market for forest products has not developed in efficiency and stability to the extent frequently found for many commodities, and greater efficiency in the market mechanism is needed. Prices received for similar forest products in a given locality may differ greatly.

The descriptive research has been useful in identifying problems and development of methodology suitable for use in finding solutions to problems confronted, but a more comprehensive attack seeking greater depth is needed and such studies, now underway, are being planned. Regional project NCM-27, Timber Products Marketing in Selected Areas of the North Central Region, is being replaced by NCM-34, Factors Influencing the Use of Wood Materials in the Manufacture of Furniture. This new study will not only attempt to determine types of raw materials used, sources, and technical requirements but will attempt to determine factors influencing decisions in choice of raw material for furniture manufacture. Regional project WM-42, The Market Structure and Marketing Practices Associated with Initial Processors of Timber Obtained from Small Woodlands, is being replaced by regional project WM-50, Intra-regional Competition in Lumber and Plywood Marketing in the Western United States. Trends and determinate factors associated with the trends will be studied.

More research is needed in developing predicative models. An example of such research is a study being conducted by the Oregon station on the demand and supply relationships of plywood. Techniques being developed in this study will be useful in making quantitative analysis for demand and supply relationships for other forestry products.

A total of 37.6 professional man-years is being devoted to this broad area of work.

Progress--USDA and Cooperative Programs

a. Efficient production saves markets for lumber. Alabama now has only one-fifth as many sawmills as were operating in 1946, but average output per mill has doubled. A study of 47 sawmills cutting from 12 to over 55 thousand board feet of lumber per day indicated that the competitive strength and survival of sawmill operation depends upon substitution of capital equipment for man power to reduce waste, lower costs, and better meet market and consumer demands. Investments in new equipment such as mobile log and lumber handling machines, automatic carriages, and resaws increased output and reduced costs in the sample mills. Dry kilns, planers, and other finishing machines gave versatility needed to take advantage of market opportunities. Widespread installation of log debarkers and chippers added $6 to $8 of gross income per thousand board feet of lumber produced through sale of chips from slabs and edgings.

This study also showed that in many cases equipment is not being used to full advantage. Waste due to mis-cut and over-sized lumber still equalled about 10 percent of the volume of salable lumber produced. Improved log-making and log buying practices, more accurate cost accounting, and better marketing and distribution offer additional opportunities to increase productivity, sales, and net returns.

b. Production and marketing of lumber in Ohio and Kentucky hill country. A study of lumber production and marketing by 40 circular sawmills in southeastern Ohio and eastern Kentucky showed that the average mill operated 176 days per year and produced 8,400 board feet of lumber daily with eight millworkers. Red and white oaks accounted for 72 percent of all stumpage and log purchases, and yellow-poplar for 25 percent. Average log costs amounted to $47 per M bd. ft., and receipts for products sold averaged $84 per M bd. ft., leaving $37 per M bd. ft. to cover manufacturing and marketing costs, and profit and risk. Prices received varied substantially among mills and were closely associated with marketing efforts expended. Results of this study and a related study of lumber purchases by industrial users in nearby States indicated that the stability of lumber markets and prices received are strongly influenced by accuracy of manufacture, conformance to grade

specifications, and ability to meet delivery schedules.

c. Changing role of retail dealers in distribution and marketing of lumber. The retail lumber dealer has long played a primary role in the distribution and marketing of lumber and other wood products, but lumber is now generally sold with other materials, often with lessened marketing efforts by the dealer. Roughly half the retailer's sales dollar is still from lumber but dealers are rapidly increasing the variety of supplemental lines of merchandise. Numbers of retail yards also have risen greatly to 34,867 in 1958. Most of this growth was in small, suburban yards. The reatiler's share of the total market for new home construction has been cut sharply by direct mill to contractor sales and by increased production of manufactured homes. Convenience, service, and liberal credit offered by retailers have helped them keep the business of small builders, but most retail yard sales are now for home improvement and repairs. Most dealers prefer lumber delivered in strapped bundles for easier and cheaper handling, and large numbers now sell prefinished products and precut and prefabricated components.

d. Factors affecting location of wood-using industries. A study covering four wood-using industries of the northern Appalachians--lumber, furniture, particleboard, and pulp--showed that the cost of wood, labor, and transportation are the most important production factors in deciding the choice of location for new production facilities. Other factors such as State and local taxes, local financial assistance, and the cost of industries sites were found to be of much less importance for all four industries. The results of this study will be especially useful to development agencies in selecting industrial prospects and furnishing them with information about the factors most important in their location decision.

e. Wood use in mobile homes. This study, made as part of continuing investigations of wood use in residential construction, indicated that mobile homes are a rapidly growing market for wood. Between 1960 and 1963, for example, annual production increased over 35 percent to 142,870 units. Wood is the favored material for both framing and interior finish by most mobile home manufacturers. Currently wood use per unit includes an average of 1,800 board feet of lumber and 1,840 square feet (3/8-inch basis) of plywood. Substantial quantities of wood-based insulation board, hardboard, and particleboard are also used. With expected further increases in annual production, and the growing popularity of larger "expandable" and "double wide" units, the outlook for wood use by this industry is bright.

f. The competitive position of hardwood flooring. A general analysis of hardwood flooring production and use shows that this industry has consumed about 20 percent of all hardwood lumber produced annually during recent years--nearly nine-tenths of it the lower grades of red and white oak from the southern and Appalachian hardwood regions. Use of hardwood flooring per unit of residential construction has been declining steadily, however, since 1955. This loss has been due primarily to the difficulties, real or imagined, of installing hardwood flooring on concrete slabs, and the opinions of architects, builders, and homemakers regarding the relative ease and cost of maintaining wood and other types of floors. Studies are underway to develop factual information about these two factors and to determine opportunities for expanding markets for wood floors by developing improved systems of installation and maintenance, improved designs, and increased efficiencies in production and marketing.

g. Wood use in furniture increasing. Furniture manufacture consumed substantial volumes of timber products, and is an especially important market for the Nation's abundant supplies of hardwoods. Recently completed studies show, for example, that more than one-quarter of the volume of hardwood lumber produced in the United States during 1960 was used in the manufacture of furniture. More than 80 percent of the lumber used in furniture was hardwood.

Due to an increased efficiency in using materials, the substitution of metals, plastics, and other materials for wood, changes in styles and designs, and other factors, the volume of wood used in furniture has not increased as rapidly during recent years as has the value of furniture shipments. Nevertheless factors of style and frequent design changes give wood some advantages over most competing materials and the trend in wood use has been upward. In 1960 this industry used 2.3 billion board feet of lumber, 1.0 billion square feet (3/8-inch basis) of veneer and plywood, 304 million square feet (1/8-inch basis) of hardwood, and 65 million square feet (3/4-inch basis) of particleboard.

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WORK AND LINE PROJECTS, TIMBER MANAGEMENT RESEARCH DIVISION
FOREST SERVICE, U. S. D. A.

May 1, 1963 to April 30, 1964

Work and Line Project Number		Work and Line Project Titles	Work Locations	Line Projects Summary Index
CPO	FS			
		SILVICULTURE OF EASTERN FOREST TYPES		
FS 1 1-1 (LS)	FS-LS-1101	Site requirements of Lake States forest species	St. Paul, Minnesota	
FS 1 1-2 (LS)	FS-LS-1102	Silviculture of northern hardwoods	Marquette, Michigan	I, A-2
FS 1 1-3 (LS)	FS-LS-1103	Silviculture of northern conifers and aspen	Grand Rapids, Minn.	I, A-4, A-5, A-8
FS 1 1-4 (LS)	FS-LS-1104	Silviculture of mixed hardwoods	East Lansing, Mich.	I, A-5
FS 1 1-5 (LS)	FS-LS-1105	Planting and plantation management of Lake States conifers	Cadillac, Michigan	I, B-1
FS 1 1-6 (CS)	FS-CS-1101	Establishment of hardwood plantations	Ames, Iowa	
FS 1 1-7 (CS)	FS-CS-1102	Silviculture of upland hardwoods	Athens, Ohio	I, A-2
FS 1 1-8 (CS)	FS-CS-1103	Silviculture of high-value hardwoods	Bedford, Indiana	I, A-2, A-5
FS 1 1-9 (CS)	FS-CS-1104	Silviculture of mixed mountain hardwood types	Berea, Kentucky	I, A-2
FS 1 1-10 (CS)	FS-CS-1105	Silviculture of bottomland and upland mixed hardwoods	Carbondale, Illinois	I, A-2, A-5, C-2
FS 1 1-11 (CS)	FS-CS-1106	Silviculture of oak-hickory and mixed oak types	Columbia, Missouri	I, A-2
FS 1 1-12 (NE)	FS-NE-1101	Silviculture of spruce-fir and associated hardwoods, and white birch	Brewer and Orono, Maine	
FS 1 1-13 (NE)	FS-NE-1102	Planting and seeding of northern hardwoods	Burlington, Vermont	
FS 1 1-14 (NE)	FS-NE-1103	Silviculture of northern Appalachian hardwoods	Elkins, West Virginia	I, A-4, A-5, C-1
FS 1 1-15 (NE)	FS-NE-1104	Silviculture of beech-birch-maple type in the Northeast	Laconia, N. H.	I, B-3
FS 1 1-16 (NE)	FS-NE-1105	Silviculture of eastern white pine	Laconia, N. H.	I, A-5
FS 1 1-17 (NE)	FS-NE-1106	Silviculture of Coastal Plain and Piedmont forests of the Northeast	New Lisbon, N. J.	I, A-1, A-4, A-5
FS 1 1-19 (NE)	FS-NE-1108	Silviculture of Allegheny hardwoods	Warren, Pennsylvania	I, A-5, C-1
FS 1 1-20 (SE)	FS-SE-1101	Silviculture of shortleaf pine-Virginia pine-upland hardwoods	Charlottesville, Va.	I, A-2, A-5
FS 1 1-21 (SE)	FS-SE-1102	Silviculture of southern Appalachian hardwoods, and hardwood tree improvement	Asheville, N. C.	
FS 1 1-22 (SE)	FS-SE-1103	Silviculture and soils in relation to health and growth of trees	Durham, N. C.	
FS 1 1-23 (SE)	FS-SE-1104	Physiology of flowering and seed production	Durham, N. C.	
FS 1 1-25 (SE)	FS-SE-1106	Silviculture of Coastal Plain timber types	Charleston, S. C.	I, A-2, A-6, B-1
FS 1 1-26 (SE)	FS-SE-1107	Silviculture of southern Piedmont hardwoods	Athens, Georgia	I, A-2, A-3, C-1
FS 1 1-27 (SE)	FS-SE-1108	Silviculture of Piedmont loblolly pine, including plantation management	Macon, Georgia	I, B-1
FS 1 1-28 (SE)	FS-SE-1109	Southern pine seed research, tree improvement, and nursery practice	Macon, Georgia	I, A-2
FS 1 1-29 (SE)	FS-SE-1110	Silviculture of longleaf-slash pine type	Olustee, Florida	I, A-8, D-1
FS 1 1-30 (SO)	FS-SO-1102	Artificial regeneration of southern pines	Alexandria, La.	I, A-5, C-2
FS 1 1-31 (SO)	FS-SO-1106	Silviculture of southern hardwoods	Stoneville, Miss.	I, A-1, A-2, C-2
FS 1 1-32 (SO)	FS-SO-1107	Silviculture of loblolly-shortleaf pine type of the interior South	Crossett, Ark.	
FS 1 1-33 (SO)	FS-SO-1101	Silviculture of the Ozark pine type	Harrison, Ark.	
FS 1 1-34 (SO)	FS-SO-1103	Longleaf pine silviculture, and pine regeneration on sandhills	Marianna, Florida	I, A-3, A-4

WORK AND LINE PROJECTS, TIMBER MANAGEMENT RESEARCH DIVISION
FOREST SERVICE, U. S. D. A.

May 1, 1963 to April 30, 1964

Work and Line Project Number		Work and Line Project Titles	Work Locations	Line Projects Summary Index
CPO	FS			
		SILVICULTURE OF EASTERN FOREST TYPES (continued)		
FS 1 1-35 (SO)	FS-SO-1104	Silviculture of tension-zone pine-hardwood types	Nacogdoches, Texas	I, A-2, A-3, A-5, A-6
FS 1 1-36 (SO)	FS-SO-1105	Silviculture of Cumberland Plateau pine and hardwood types	Sewannee, Tennessee	I, A-5
FS 1 1-37 (ITF)	FS-ITF-1101	Silviculture in Puerto Rico and the Virgin Islands	Rio Piedras, P. R.	I, A-2, A-8
FS 1 1-38 (WO)	FS-WO-1101	Nutrition and growth of forest trees	Washington, D. C.	I, A-8
		Pioneering research on physiology of wood formation	Rhinelander, Wisconsin	I, A-8
		SILVICULTURE OF WESTERN FOREST TYPES		
FS 1 2-1 (NOR)	FS-NOR-1201	Silviculture of coastal forests in Alaska	Juneau, Alaska	
FS 1 2-2 (NOR)	FS-NOR-1202	Silviculture of interior Alaska forests	Fairbanks, Alaska	
FS 1 2-3 (PNW)	FS-PNW-1201	Seeding, planting, and nursery practices in the Pacific Northwest	Portland, Oregon	
FS 1 2-4 (PNW)	FS-PNW-1202	Effects of silviculture and species composition on soil	Portland, Oregon	I, A-1
FS 1 2-5 (PNW)	FS-PNW-1203	Silviculture of lodgepole and ponderosa pines and interior mixed conifers	Bend, Oregon	I, A-3, B-1
FS 1 2-6 (PNW)	FS-PNW-1204	Silviculture of true fir-mountain hemlock and Sitka spruce-western hemlock types	Corvallis, Oregon	I, A-2, A-8, B-2
FS 1 2-7 (PNW)	FS-PNW-1205	Silviculture of the mixed sugar pine–Douglas-fir–ponderosa pine type	Roseburg, Oregon	
FS 1 2-8 (PNW)	FS-PNW-1206	Brush field reclamation	Roseburg, Oregon	
FS 1 2-9 (PNW)	FS-PNW-1207	Silviculture of young-growth Douglas-fir and related species	Olympia, Washington	I, A-5, A-8, B-1
FS 1 2-10 (PNW)	FS-PNW-1208	Prevention and control of animal damage to forest trees	Olympia, Washington	I, A-6
FS 1 2-11 (PNW)	FS-PNW-1209	Tree improvement and seed orchard management in the Northwest	Corvallis, Oregon	
FS 1 2-12 (PSW)	FS-PSW-1201	Silviculture of old-growth Sierra forests	Berkeley, Calif.	I, A-5, A-8
FS 1 2-13 (PSW)	FS-PSW-1202	Forest seeding and planting	Berkeley, Calif.	I, A-1, A-2
FS 1 2-14 (PSW)	FS-PSW-1203	Silviculture of redwood and Douglas-fir forests	Klamath, Calif.	I, A-4
FS 1 2-15 (PSW)	FS-PSW-1204	Silviculture of young-growth and planted forests	Redding, Calif.	
FS 1 2-16 (PSW)	FS-PSW-1205	Forest establishment and management in Hawaii	Hilo, Hawaii	
FS 1 2-17 (INT)	FS-INT-1201	Silviculture of western white pine and associated species	Moscow, Idaho	I, C-1, C-2
FS 1 2-18 (INT)	FS-INT-1202	Silviculture of ponderosa pine and interior Douglas-fir	Boise, Idaho	
FS 1 2-19 (INT)	FS-INT-1203	Silviculture of lodgepole pine	Bozeman, Montana	I, A-3
FS 1 2-20 (INT)	FS-INT-1204	Silviculture of western larch and Engelmann spruce types	Missoula, Montana	I, A-7
FS 1 2-21 (RM)	FS-RM-1201	Silviculture of spruce-fir and lodgepole pine in the central Rocky Mountains	Ft. Collins, Colo.	
FS 1 2-22 (RM)	FS-RM-1202	Silviculture of mixed conifers of the Southwest and the Rocky Mountain aspen type	Ft. Collins, Colo.	

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Work and Line Project Number		Work and Line Project Titles	Work Locations	Line Projects Summary Index
CPO	FS			
		SILVICULTURE OF WESTERN FOREST TYPES (continued)		
FS 1 2-23(RM)	FS-RM-1203	Silviculture of ponderosa pine in the Southwest	Flagstaff, Arizona	I, A-2, A-4
FS 1 2-24(RM)	FS-RM-1204	Windbreak establishment and management in the central and southern Great Plains	Lincoln, Nebraska	
FS 1 2-25(RM)	FS-RM-1205	Silviculture of ponderosa pine in the Black Hills	Rapid City, S. D.	I, A-2, A-5, B-1
FS 1 2-26(LS)	FS-LS-1201	Shelterbelt establishment and management including tree improvement aspects	Bottineau, N. D.	I, A-7
		FOREST MENSURATION		
FS 1 3-1(PNW)	FS-PNW-1301	Mensuration and related timber management techniques in the Northwest	Portland, Oregon	
FS 1 3-2(INT)	FS-INT-1301	Mensuration and related timber management techniques in the northern Rocky Mountains	Moscow, Idaho	I, B-2
FS 1 3-3(NE)	FS-NE-1301	Mensuration studies of northeastern conifers and hardwoods	Upper Darby, Pa.	
FS 1 3-4(SO)	FS-SO-1301	Mensuration studies of southern pines and hardwoods	Hot Springs, Ark.	
FS 1 3-5(RM)	FS-RM-1301	Mensuration and related timber management techniques in the central Rocky Mountains and Southwest	Ft. Collins, Colo.	I, B-2
FS 1 3-6(PSW)	FS-PSW-1301	Mensuration and related timber management techniques in the Pacific Southwest	Berkeley, Calif.	I, B-2
	FS-SE-1301	Mensuration studies of the forests of the Southeast	Asheville, N. C.	
		Pioneering research unit in Forest Mensuration	Berkeley, Calif.	I, B-2
		FOREST GENETICS		
FS 1 4-1(PSW)	FS-PSW-1401	Genetics of western conifers	Berkeley, Calif.	I, C-1
FS 1 4-2 (LS)	FS-LS-1401	Genetics of northern conifers and hardwoods	Rhinelander, Wis.	
FS 1 4-3(NE)	FS-NE-1401	Genetic improvement of conifers and hardwoods in the Northeast	Chestnut Hill, Pa.	I, A-6, C-1, D-2
FS 1 4-4(SO)	FS-SO-1401	Genetics of southern pines and hardwoods	Gulfport, Miss.	I, C-1
FS 1 4-5(WO)	FS-WO-1401	Identification, classification, and distribution of forest trees	Washington, D. C.	

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CPO	FS			
		TIMBER-RELATED CROPS		
FS 1 5-1(NE)	FS-NE-1501	Maple sap production and related tree improvement	Burlington, Vermont	I, D-2
FS 1 5-2(SE)	FS-SE-1501	Naval stores gum production and related tree improvement	Olustee, Florida	I, D-1
		PL 480 PROJECTS		
S3-FS-2		Breeding investigations in trees with perfect flowers, as in Eucalyptus	Rio Claro, Brazil	
S3-FS-6		Mineral nutrition of Pinus elliottii	San Paulo, Brazil	
S4-FS-3		Investigation in rooting and growth induction of short shoots of Pinus radiata	Santiago, Chile	I, C-1
S4-FS-6		Biosynthesis of terpenes in Pinus radiata	Santiago, Chile	
S4-FS-7		Effect of growth substances in pine meristems	Santiago, Chile	
S5-FS-4		Basic studies of the physiological changes in the transition from juvenile to mature stage in certain forest trees	Bogota, Colombia	
E8-FS-1		Basic studies into the important factors controlling the quantity and quality of natural seed crops of forest trees	Helsinki, Finland	
E8-FS-31		The role of mycorrhizae	Helsinki, Finland	
E8-FS-36		The importance of soil temperature, height of water table, and microclimate as the growth factors of pine, spruce, and birch	Helsinki, Finland	
E8-FS-44		Genetics of flowering of forest trees: The problem of fertilization	Helsinki, Finland	I, C-1
E8-FS-45		Population study concerning spruce with special reference to the variation in the characteristics of wood	Helsinki, Finland	
E8-FS-46		The value of alder in adding nitrogen in forest soils	Helsinki, Finland	I, A-1
E8-FS-47		Induced polyploidy and other mutations in birch, Betula spp.	Turku, Finland	
E8-FS-48		DNA and RNA studies on Scotch pine with special attention to finding a method to increase flowering	Turku, Finland	
E8-FS-49		The role of soil fungi in the formation of different humus types, especially in raw humus formation in northern forests	Helsinki, Finland	

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CPO	FS			
		PL 480 PROJECTS (continued)		
E8-FS-50		Pollen dispersal and its significance in silviculture and genetics	Helsinki, Finland	I, C-1
E8-FS-51		Effect of silvicultural practices upon the arthropod, annelid, and nematode populations in forest litter and soil	Helsinki, Finland	
E11-FS-1		Reconnaissance breeding in certain hard pines of the Mediterranean area	Thessaloniki, Greece	
E11-FS-2		Nutritional studies of forest trees under various soil and nutrient solution conditions	Athens, Greece	
A7-FS-10		Investigations on mycorrhiza-forming fungi with special reference to conifers in India	Dehra Dun, India	
A7-FS-12		Cytology of some Himalayan hardwoods and cytological and morphological differences or similarities in ecotypes or clines of Himalayan forest trees	Chandigarh, India	
A10-FS-5		Factors controlling the annual rhythm of wood production	Jerusalem, Israel	
A10-FS-7		Mechanisms of drought tolerance and drought avoidance in conifers of the Mediterranean zone and the arid West of the U. S.	Rehovot, Israel	
A10-FS-8		The development of techniques for the vegetative propagation of pine trees by means of needle fascicles	Jerusalem, Israel	
A10-FS-10		Effect of transpiration retardants on certain physiological processes of forest seedlings and other plants	Jerusalem, Israel	I, A-2
E15-FS-3		Factors affecting the difficult rooting of cuttings in some poplars (i. e. P. deltoides v. angulata, P. alba, P. tremula) and their hybrids	Rome, Italy	
E15-FS-6		The problem of incompatibility in grafting of forest trees, especially pines	Florence, Italy	
E15-FS-8		Limiting factors of the photosynthetic efficiency in a forest tree (Popular canadensis).	Milan, Italy	
A13-FS-1		The fundamental mechanism of root-primordia formation of cuttings	Suwon, Korea	I, C-1
E21-FS-1		Influence of soil, ground water table and precipitation on the rate of increment of Pinus silvestris trees and stands in age classes I-III	Warsaw, Poland	
E21-FS-17		Investigations of pure culture of mycorrhizal fungi of pine (Pinus sylvestris L.)	Warsaw, Poland	

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CPO	FS			
		PL 480 PROJECTS (continued)		
E21-FS-20		Population study of spruce in Poland	Warsaw, Poland	
E21-FS-22		Influence of sowing of lupine on tree growth	Warsaw, Poland	
E21-FS-23		Decomposition of forest litter in stands as related to degree of thinning	Warsaw, Poland	
E21-FS-24		Studies in wood formation	Warsaw, Poland	
E21-FS-26		A survey of endogenous growth substances in certain forest trees	Torun, Poland	
E21-FS-31		Studies on the variability of photosynthesis of pine trees during development under different conditions of growth	Warsaw, Poland	
E25-FS-14		Ontogenesis of enzymes induced in pine seed through cold stratification	Madrid, Spain	
E25-FS-15		Minor elements distribution in cellular fluids of floral and folian tissue of trees	Madrid, Spain	
E25-FS-16		Isolation and identification of plant hormones associated with callus and root formation	Santiago, Spain	
E25-FS-20		The determination of levels of boron, manganese and molybdenum sufficient for growth of Monterey Pine (Pinus radiata) and the characterization of deficiency symptoms for these three elements	Madrid, Spain	
E25-FS-23		Spanish contribution to multilingual forest terminology with Hispano-American terms	Madrid, Spain	
A6-FS-2		The genus Abies	Taipei, Taiwan	

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CPO	FS			
		FOREST SOIL AND WATER RESEARCH		
FS 16-31 (SE)	FS-SE-1601	Water yield improvement, mountains - Piedmont	Franklin, North Carolina	II, A-1-c, A-3-a
FS 16-32 (SE)	FS-SE-1602	Wetland improvement	Charleston, S. Carolina	
FS 16-34 (SO)	FS-SO-1601	Water timing - Ozark-Ouachita	Harrison, Arkansas	
FS 16-35 (SO)	FS-SO-1602	Coastal Plain hydrology - South	Oxford, Mississippi	II, A-3-a
FS 16-36 (SO)	FS-SO-1603	Watershed rehabilitation - Coastal Plain	Oxford, Mississippi	
FS 16-37 (SO)	FS-SO-1604	Management of erosive watersheds	Oxford, Mississippi	
FS 16-38 (RM)	FS-RM-1608	Water yield, soil stabilization	Rapid City, South Dakota	II, A-3-d
A-10-FS-9	(PL-480)	Monographic revision of the genus Tamarix	Israel	II, A-5-a
		FOREST RECREATION RESEARCH		
FS 19-1 (PSW)	FS-PSW-1901	Recreation use - California	Berkeley, California	II, B-1, 2
FS 19-2 (LS)	FS-LS-1901	Recreation - LS	St. Paul, Minnesota	II, B-1, 2, 3
FS 19-3 (LS)	FS-LS-1902	Lake States-University of Michigan Coop. recreation unit	Ann Arbor, Michigan	II, B-3
FS 19-4 (CS)	FS-CS-1901	Small woodland recreation	Columbus, Ohio	II, B-3
FS 19-5 (NE)	FS-NE-1901	Recreation research - Northeast	Warren, Pennsylvania	II, B-2, 3
FS 19-6 (NE)	FS-NE-1902	Syracuse recreation project	Syracuse, New York	II, B-2
FS 19-8 (INT)	FS-INT-1901	Recreation planning and management - INT	Ogden, Utah	II, B-1
FS 19-9 (INT)	FS-INT-1902	Forest recreation research unit in cooperation with Utah State University	Logan, Utah	II, B-2
FS 19-11 (PNW)	FS-PNW-1901	Wilderness recreation dynamics	Portland, Oregon	II, B-2, 3
FS 19-13 (SE)	FS-SE-1901	Forest recreation management	Asheville, North Carolina	II, B-1, 2
FS 19-15 (RM)	FS-RM-1901	Forest recreation research - Rocky Mountains	Fort Collins, Colorado	II, B-2
		RANGE MANAGEMENT RESEARCH		
FS 17-1 (PNW)	FS-PNW-1701	Range ecology and management - Northwest	La Grande, Oregon	II, C- 2c, 3a
FS 17-3 (PSW)	FS-PSW-1701	Woodland and chaparral conversion management	Berkeley, California	
FS 17-4 (PSW)	FS-PSW-1702	Management of annual plant and related ranges	Fresno, California	II, C- 3b
FS 17-5 (PSW)	FS-PSW-1703	Management bunchgrass range	Berkeley, California	II, C- 2c
FS 17-7 (INT)	FS-INT-1701	Sagebrush, cheatgrass, and granitic soil ranges	Boise, Idaho	II, C- 3a, 4
FS 17-8 (INT)	FS-INT-1702	Northern Rocky Mountain grasslands	Bozeman, Montana	II, C- 1a, 2c
FS 17-9 (INT)	FS-INT-1703	Salt-desert shrub, sagebrush-grass, and pinyon-juniper ranges	Provo, Utah	II, C- 3b

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CPO	FS			
		FOREST SOIL AND WATER RESEARCH		
FS 16-1 (NOR)	FS-NOR-1601	Erosion and sedimentation, coastal forests	Juneau, Alaska	II, A-2-a
FS 16-2 (PNW)	FS-PNW-1601	Water yield and erosion - Columbia River	Wenatchee, Washington	II, A-1-b, A-1-c, A-2-a, A-3-b
FS 16-3 (PNW)	FS-PNW-1602	Watershed logging methods and streamflow - western Cascades	Corvallis, Oregon	II, A-1-c, A-2-a A-2-b
FS 16-4 (PSW)	FS-PSW-1601	Snow management research	Berkeley, California	II, A-1-b
FS 16-5 (PSW)	FS-PSW-1602	Water source hydrology	Berkeley, California	II, A-1-b
FS 16-6 (PSW)	FS-PSW-1603	Water yield - lower conifer	Berkeley, California	II, A-1-c
FS 16-7 (PSW)	FS-PSW-1604	Flood and sediment - Southwest	Glendora, California	II, A-3-d
FS 16-8 (PSW)	FS-PSW-1605	Water yield - Southwest	Glendora, California	II, A-1-c
FS 16-9 (PSW)	FS-PSW-1606	Water yield - Hawaii	Honolulu, Hawaii	II, A-2-a
FS 16-10 (INT)	FS-INT-1601	Snowmelt flood and sediment reduction	Moscow, Idaho	II, A-1-b, A-2-b
FS 16-11 (INT)	FS-INT-1602	Soil stabilization, logging - northern Rockies	Boise, Idaho	II, A-2-a, A-2-b
FS 16-12 (INT)(R)	FS-INT-1603 (Rev.)	Watershed rehabilitation and protection - high rangelands	Logan, Utah	II, A-2-c, A-3-b
FS 16-14 (INT)	FS-INT-1605	Water yield improvement - Great Basin and Missouri	Logan, Utah	II, A-1-b
FS 16-15 (INT) 1/	FS-INT-1606	Rain-on-snow flood reduction	Reno, Nevada	
FS 16-16 (RM)	FS-RM-1601	Alpine snow and avalanche research	Fort Collins, Colorado	II, A-1-a
FS 16-17 (RM)	FS-RM-1602	Water yield snowpack timber - Rocky Mountains	Fort Collins, Colorado	II, A-1-b, A-3-b
FS 16-18 (RM)	FS-RM-1603	Water yield, soil stabilization - Big Horn, North Platte	Laramie, Wyoming	II, A-1-b
FS 16-19 (RM)	FS-RM-1604	Watershed rehabilitation - Southwest	Albuquerque, New Mexico	II, A-2-c
FS 16-20 (RM)	FS-RM-1605	Riparian and wet sites	Tempe, Arizona	II, A-1-c
FS 16-21 (RM)	FS-RM-1606	Water yield upland areas	Tempe, Arizona	II, A-1-b
FS 16-22 (LS)	FS-LS-1601	Runoff and erosion reduction - nonglaciated	La Crosse, Wisconsin	II, A-3-a
FS 16-23 (LS)	FS-LS-1602	Bog and swamp hydrology	Grand Rapids, Minnesota	II, A-1-b, A-4-a
FS 16-24 (LS)	FS-LS-1603	Ground water hydrology and streambank erosion	Cadillac, Michigan	II, A-1-b, A-2-a
FS 16-25 (CS)	FS-CS-1601	Strip-mined area restoration	Berea, Kentucky	II, A-3-c
FS 16-26 (CS)	FS-CS-1602	Management of storm runoff	Columbus, Ohio	
FS 16-27 (NE)	FS-NE-1601	Water yield improvement - New England	Laconia, New Hampshire	II, A-1-b
FS 16-28 (NE)	FS-NE-1602	Floods, erosion, and water yield - central Appalachians	Parsons, West Virginia	II, A-1-c
FS 16-29 (NE)	FS-NE-1603	Municipal watersheds	New Lisbon, New Jersey	II, A-1-c
FS 16-30 (NE)	FS-NE-1604	Stream regimen and water yields - Northeast	Syracuse, New York	II, A-1-b

1/ Line Project discontinued, work included in FS 16-12 (INT)(R) FS-INT-1603 (Rev.)

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CPO	FS			
		RANGE MANAGEMENT RESEARCH		
FS 17-10 (INT)	FS-INT-1704	Management of mountain herbland, brushland, and aspen ranges	Logan, Utah	II, C- 2c, 3a, 5
FS 17-11 (RM)	FS-RM-1701	Mountain ranges - central Rockies	Fort Collins, Colorado	II, C- 1a, 2c, 3b, 5
FS 17-12 (RM)	FS-RM-1702	Range biometry	Fort Collins, Colorado	II, C- 2b
FS 17-13 (RM)	FS-RM-1703	Alpine and subalpine ranges	Laramie, Wyoming	
FS 17-14 (RM)	FS-RM-1704	Southwestern seeded ranges	Albuquerque, New Mexico	II, C- 3b
FS 17-15 (RM)	FS-RM-1705	Southwestern chaparral, woodland, and forest ranges	Flagstaff, Arizona	II, C- 1a, 3b
FS 17-16 (RM)	FS-RM-1706	Semidesert cattle ranges	Tucson, Arizona	II, C- 3b
FS 17-17 (CS)	FS-CS-1701	Range evaluation and management	Columbia, Missouri	II, C- 3b, 4
FS 17-18 (SE)	FS-SE-1701	Integrated range-timber-wildlife management	Fort Myers, Florida	II, C- 2a, 3a, 4
FS 17-19 (SO)	FS-SO-1701	Southern pine cattle ranges	Alexandria, Louisiana	II, C- 3a
FS 17-20 (WO)	FS-WO-1701	Range plant taxonomy	Washington, D.C.	
FS 17-21 (WO)	FS-WO-1702	Range inventory and evaluation	Washington, D.C.	
A10-FS-6	(PL-480)	Germination of seeds of desert plants	Israel	II, C- 1a
E25-FS-1	(PL-480)	Studies of botany, ecology, and biology of the principal species in mountain pastures of semiarid regions	Spain	
		WILDLIFE HABITAT RESEARCH		
FS 18-1 (PNW)	FS-PNW-1801	Big game habitat - Pacific Northwest	La Grande, Oregon	II, C- 1a, 2a
FS 18-3 (PSW)	FS-PSW-1801	Deer habitat - California	Berkeley, California	II, C- 1a, 2b, 2c
FS 18-4 (INT)	FS-INT-1801	Deer winter range - Idaho	Boise, Idaho	II, D- 1
FS 18-5 (INT)	FS-INT-1802	Northern Rockies forest wildlife habitat	Missoula, Montana	
FS 18-6 (INT)	FS-INT-1803	Game range restoration, and wildlife-livestock relations	Provo, Utah	II, D- 1
FS 18-7 (RM)	FS-RM-1801	Forest game and fish habitat - central Rockies	Fort Collins, Colorado	II, D- 1
FS 18-8 (RM)	FS-RM-1802	Wildlife habitat - southwestern vegetation types	Tempe, Arizona	II, D- 1, 2
FS 18-9 (RM)	FS-RM-1803	Wildlife habitat - Black Hills	Rapid City, South Dakota	II, D- 1, C- 1a
FS 18-11 (LS)	FS-LS-1801	Conifer-aspen wildlife habitat - Lake States	St. Paul, Minnesota	
FS 18-13 (NE)	FS-NE-1801	Wildlife habitat in northeastern forests	Warren, Pennsylvania	II, D- 1, 2, C- 2b
FS 18-15 (SE)	FS-SE-1801	Forest wildlife habitat in the Southeast	Asheville, North Carolina	II, D- 2
FS 18-16 (SO)	FS-SO-1801	Wildlife habitat in southern forests	Nacogdoches, Texas	II, D- 2

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CPO	FS			
		FOREST FIRE		
FS 2 1-1 (NOR)	FS-NOR-2101	Fire Control Systems	Fairbanks, Alaska	III A, 2-b
FS 2 1-2 (PNW)	FS-PNW-2101	Fire Control and Use	Portland, Oregon	----
FS 2 1-3 (PNW)	FS-PNW-2102	Fire Weather	Portland, Oregon	III A, 1-d
FS 2 1-4 (PSW)	FS-PSW-2101	Conflagration Control	Berkeley, California	III A, 3-c
FS 2 1-5 (PSW)	FS-PSW-2102	Fire Control Systems	Berkeley, California	III A, 3-c
FS 2 1-6 (PSW)	FS-PSW-2103	Fire Chemistry	Berkeley, California	III A, 1-a
FS 2 1-7 (PSW)	FS-PSW-2104	Fuel Break	Riverside, California	----
FS 2 1-8 (PSW)	FS-PSW-2105	Fire Prevention	Riverside, California	III A, 2-a
FS 2 1-9 (PSW)	FS-PSW-2106	Improvement of Fire Control Methods	Riverside, California	III A, 3-d
FS 2 1-10(PSW)	FS-PSW-2107	Fire Behavior	Riverside, California	III A, 1-b, d
FS 2 1-11(PSW)	FS-PSW-2108	(Project to come in later)	Riverside, California	----
FS 2 1-12(INT)	FS-INT-2101	Project Skyfire	Missoula, Montana	III A, 2-b
FS 2 1-13(INT)	FS-INT-2102	Fire Control Systems	Missoula, Montana	III A, 2-b, 3-a
FS 2 1-14(INT)	FS-INT-2103	Fire Physics	Missoula, Montana	III A, 1-c
FS 2 1-15(INT)	FS-INT-2104	Fire Behavior	Missoula, Montana	III A, 1-c
FS 2 1-16(RM)	FS-RM- 2101	Fire Control	Fort Collins, Colorado	----
FS 2 1-17(RM)	FS-RM- 2102	Fire Use	Flagstaff, Arizona	III A, 4-c
FS 2 1-18(LS)	FS-LS- 2101	Fire Control Systems	St. Paul, Minnesota	III A, 3-c, d
FS 2 1-19(NE)	FS-NE- 2101	Fire Control Planning	Upper Darby, Pennsylvania	----
FS 2 1-20(SE)	FS-SE- 2101	Fire Use	Macon, Georgia	III A, 4-a, b
FS 2 1-21(SE)	FS-SE- 2102	Fire Control	Macon, Georgia	III A, 3-d
FS 2 1-22(SE)	FS-SE- 2103	Fire Potential	Macon, Georgia	III A, 1-b, d
FS 2 1-23(SE)	FS-SE- 2104	Fire Environment	Macon, Georgia	III A, 1-a
FS 2 1-24(SE)	FS-SE- 2105	Fire Models	Macon, Georgia	III A, 1-c
FS 2 1-25(CS)	FS-CS- 2101	Hardwood Fire Control	Salem, Missouri	----
FS 2 1-26(SO)	FS-SO- 2101	Fuels and Fire Control	Alexandria, Louisiana	III A, 1-d
FS 2 1-27(SO)	FS-SO- 2102	Fire Prevention	Alexandria, Louisiana	III A, 2-a
FS 2 1-28(WO)	FS-WO- 2101	National Fire Danger Rating	Asheville, North Carolina	III A, 3-b
	P. L. 480			
-----	E-25-FS-13	Open Fires and Transport of Fire Brands	Madrid, Spain	----

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CPO	FS			
		FOREST INSECTS		
FS 2 2-1(NOR)	FS-NOR-2201	Forest Insects, Coastal Forests	Juneau, Alaska	III, B-4-b, 4-c
FS 2 2-3(PNW)	FS-PNW-2201	Bark beetles, sucking insects, cone and seed insects, wood products insects.	Portland, Oregon	III, B-1-a, 4-a, 4-e
FS 2 2-4(PNW)	FS-PNW-2202	Defoliating insects, regeneration insects, range insects.	Portland, Oregon	III, B-1-b, 2-b, 4-b, 4-e
FS 2 2-5(PNW)	FS-PNW-2203	Diseases of western forest insects.	Corvallis, Oregon	III, B-1-b
FS 2 2-6(PNW)	FS-PNW-2204	Physiology and biochemistry of western forest insects.	Corvallis, Oregon	III, B-4-a
FS 2 2-7(PNW)	FS-PNW-2205	Biological control of western forest insects.	Corvallis, Oregon	III, B-1-a
FS 2 2-8(PSW)	FS-PSW-2201	Toxicology, physiology and host resistance of forest insects in California.	Berkeley, California	III, B-1-c, 2-b
FS 2 2-9(PSW)	FS-PSW-2202	Biology, ecology and control of forest insects in California.	Berkeley, California	III, B-1-a, 1-b, 4-b, 4-c, 4-e
FS 2 2-11(RM)	FS-RM-2201	Biology, ecology and control of forest insects in Central Rockies and southern Great Plains:	Ft. Collins, Colorado	III, B-1-a, 1-c, 2-b
FS 2 2-12(RM)	FS-RM-2202	Biology, ecology and control of forest insects in the Southwest.	Albuquerque, New Mexico	III, 8-1-a, 1-b, 2-b
FS 2 2-13(INT)	FS-INT-2201	Biology, ecology and control of forest and range browse insects in Intermountain region:	Ogden, Utah	III, B-4-b
FS 2 2-14(INT)	FS-INT-2202	Biology, ecology and control of bark beetles in Northern Rockies.	Missoula, Montana	III, B-4-a
FS 2 2-15(INT)	FS-INT-2203	Biology, ecology and control of defoliators and regeneration insects in Northern Rockies:	Missoula, Montana	III, B-2-b, 4-b, 4-d
FS 2 2-16(LS)	FS-LS-2201	Seed and cone, aspen and shelterbelt insects in the Lake States and northern Great Plains:	St. Paul, Minnesota	III, B-4-c
FS 2 2-17(LS)	FS-LS-2202	Biology, ecology and control of forest insect defoliators in the Lake States.	St. Paul, Minnesota	
FS 2 2-18(LS)	FS-LS-2203	Biology, ecology, and control of forest plantation insects in the Lake States.	East Lansing, Michigan	III, B-4-d
FS 2 2-19(CS)	FS-CS-2201	Biology, ecology and silvicultural control of insects of forest and plantation insects in Central States.	Delaware, Ohio	III, B-4-c, 4-e
FS 2 2-20(CS)	FS-CS-2202	Physiology, toxicology and control of forest and shade trees in Central States.	Delaware, Ohio	III-B-1-c, 2-a
FS 2 2-21(CS)	FS-CS-2203	Biological control and disease vectors.	Delaware, Ohio	

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CPO	FS			
		FOREST INSECTS		
FS 2 2-22(NE)	FS-NE-2201	Biology and ecology of forest insects in the Northeast.	New Haven, Connecticut	III, B-1-a, 1-b, 4-b, 4-c, 4-d
FS 2 2-23(NE)	FS-NE-2202	Biotic control of forest insect pests in Northeast.	New Haven, Connecticut	III, B-1-b
FS 2 2-24(NE)	FS-NE-2203	Control of forest insects using synthetic chemicals.	New Haven, Connecticut	III, B-2-a, 2-b
FS 2 2-25(SE)	FS-SE-2201	Biology, ecology, control of defoliators and sucking insects in the Southeast.	Asheville, North Carolina	III, B-1-a, 4-b
FS 2 2-26(SE)	FS-SE-2202	Physiology and biochemistry of forest insects.	Durham, North Carolina	III, B-4-a, 4-e
FS 2 2-27(SE)	FS-SE-2203	Slash and longleaf seed and cone insects and insects affecting plantations and Naval Stores.	Olustee, Florida	III, B-2-b
FS 2 2-28(SE)	FS-SE-2204	Hardwood insects; insect enemies of pines in nurseries and plantations other than slash and longleaf.	Athens, Georgia	III, B-4-d
FS 2 2-30(SO)	FS-SO-2203	Biology, ecology and control of hardwood insects in Deep South.	Stoneville, Mississippi	III, B-1-a, 2-a, 2-b, 3
FS 2 2-31(SO)	FS-SO-2201	Biology, ecology and control of wood products insects.	Gulfport, Mississippi	III, B-5
FS 2 2-32(SO)	FS-SO-2202	Biology ecology and control of pine insects in Deep South.	Alexandria, Louisiana	III, B-1-a, 1-c, 2-a, 4-e
FS 2 2-33(WO)	FS-WO-2201	Aerial survey techniques research	Beltsville, Maryland	III, B-6
FS 2 2-34(WO)	FS-WO-2202	Aerial applications research	Beltsville, Maryland	III, B-2-b
FS 2 2-35(WO)	FS-WO-2203	Toxicology, pathology and physiology of forest insects.	Beltsville, Maryland	III, B-1-b, 2-b, 4-b
FS 3 2-10(FPL)	FS-FPL-3210	Wood fungus and subterranean termites	Madison, Wisconsin	III, B-5
P. L. 480				
E21-FS-2		Insects noxious to young stands of pine.	Warsaw, Poland	III-B-1-d-(4)c
E21-FS-3		Research on the Growth and Development and Disease Susceptibility of some Species of Trees from the U.S.A. to be planted in certain Climatic Regions of Poland.	Warsaw, Poland	III-B-4-f-(4)
E21-FS-6		Investigations into the activity of the parasite, Trichogramma embryophagum (Hart) introduced into the forest environment with special attention to its capacity for spreading.	Poznan, Poland	III-B-1-d-(4)b

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CPO	FS			
P. L. 480				
E21-FS-7		Studies in the Development of Improved Strains of Parasites of Forest Insects.	Poznan, Poland	III-B-1-d-(4)a
E25-FS-3		Pests of poplars and preventive and curative methods of control.	Madrid, Spain	III-B-4-f-(1)
E25-FS-10		The study of parasites, predators and diseases of the Gypsy Moth and the possibility of their application in the biological control.	Madrid, Spain	
E30-FS-2		Study of the polyhedral virus disease of the gypsy moth.	Zemun, Yugoslavia	
A6-FS-4		Biological study of the more important insect pests attacking genus Pinus introduced from USA.	Taiwan, China	III-B-4-f(2)
A7-FS-7		Survey for natural enemies of Chermes spp. attacking silver fir and spruce in the Himalayas.	Bangalore, India	III-B-1-d(2)b
A7-FS-8		Survey of parasites for gypsy moth.	Bangalore, India	III-B-1-d(2)a
A7-FS-25		Survey for natural enemies of Hypsipyla spp. in India.	Bangalore, India	
A17-FS-1		Survey of Insect Fauna of the Forests of Pakistan.	Peshawar, West Pakistan	III-B-4-f(3)
A17-FS-5		Investigations on the predators of Adelges (an aphid on fir).	Rawalpindi, Pakistan	III-B-1-d(3)a
A17-FS-6		Studies on the natural enemies of insect pests of West Pakistan forests.	Rawalpindi, Pakistan	III-B-1-d(3)b
E8-FS-38		Orienting stimuli guiding insect pests of forests to suitable host trees.	Helsinki, Finland	III-B-4-f-(5)
S5-FS-1		Disease and insect susceptibility and species adaptability of some North American forest tree species planted in Colombia.	Medellin, Colombia	III-B-4-f-(8)
S9-FS-1		Disease and insect susceptibility and species adaptability of North American conifers planted in Uruguay	Montevideo, Uruguay	III-B-4-f-(6)

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CPO	FS			
		FOREST DISEASE		
FS 2 3-1 (PNW)	FS-PNW-2301	Forest Disease Control in NW	Portland, Oregon	III C, 3-e
FS 2 3-2 (PNW)	FS-PNW-2302	Soil Microbiology	Corvallis, Oregon	III C, 1-b, 2-a, 2-c, 2-d, 3-e
FS 2 3-3 (PNW)	FS-PNW-2303	Root Diseases	Portland, Oregon	-----
FS 2 3-4 (PNW)	FS-PNW-2304	Plantings, Pastures, People & Products	Corvallis, Oregon	III C, 1-b, 3-b
FS 2 3-5 (PSW)	FS-PSW-2301	Heartrots, Mistletoes, & White Pine Blister Rust	Berkeley, California	III C, 3-b, 3-e, 3-f
FS 2 3-6 (PSW)	FS-PSW-2302	Diseases of Seed, Seedlings, Reproduction, and Physiogenic Diseases	Berkeley, California	III C, 1-a, 1-b
FS 2 3-7 (INT)	FS-INT-2301	Native Rusts of Western Conifers	Logan, Utah	III C, 3-a
FS 2 3-8 (INT)	FS-INT-2302	Breeding Western White Pine Resistant to Blister Rust	Moscow, Idaho	III C, 3-b
FS 2 3-9 (INT)	FS-INT-2303	Diseases of Western White Pine and Antibiotic Action	Moscow, Idaho	III C, 2-b, 3-b, 3-e, 4-a, 4-f
FS 2 3-10 (RM)(R)	FS-RM-2301(R)	Diseases of Trees and Shrubs in the Central Rocky Mountains	Fort Collins, Colorado	III C, 3-d, 3-e, 3-f, 4-f, 6-a
FS 2 3-11 (RM)	FS-RM-2302	Diseases of Southwest Ponderosa Pine and Associated Species	Albuquerque, New Mexico	III C, 2-c, 2-d
FS 2 3-28 (RM)	FS-RM-2303	Diseases of Field Windbreaks and Nurseries in the Great Plains	Lincoln, Nebraska	III C, 1-b, 4-f
FS 2 3-12 (LS)	FS-LS-2301	Diseases of Northern Conifers and Shelterbelts	St. Paul, Minnesota	III C, 1-a, 3-a, 3-b, 3-d
FS 2 3-13 (LS)	FS-LS-2302	Diseases of Aspen	St. Paul, Minnesota	III C, 3-d
FS 2 3-14 (LS)	FS-LS-2303	Diseases of Northern Hardwoods	Marquette, Michigan	III C, 3-d, 3-f, 5-a, 5-b
FS 2 3-15 (CS)	FS-CS-2301	Parasitic Diseases and Heartrots	Delaware, Ohio	III C, 5-a
			Columbia, Missouri	III C, 2-a
FS 2 3-16 (CS)	FS-CS-2302	Physiogenic Diseases	Delaware, Ohio	III C, 4-e
FS 2 3-17 (NE)	FS-NE-2301	Mid-Atlantic Tree Diseases	Upper Darby, Pa.	III C, 3-d
FS 2 3-18 (NE)	FS-NE-2302	New England Tree Diseases	New Haven, Connecticut	III C, 1-a
			Laconia, New Hampshire	-----
FS 2 3-19 (SE)	FS-SE-2301	Appalachian Hardwood Diseases	Asheville, N. C.	III C, 3-d, 5-a
FS 2 3-20 (SE)	FS-SE-2302	Annosus Root Rot	Research Triangle, N. C.	III C, 2-a
			Athens, Georgia	-----
FS 2 3-21 (SE)	FS-SE-2303	Rust and Nursery Diseases	Athens, Georgia	III C, 3-c
			Macon, Georgia	III C, 3-c, 4-f
FS 2 3-22 (SE)	FS-SE-2304	Soil Borne Organisms	Athens, Georgia	III C, 1-a, 2-b, 2-c, 2-d
			Research Triangle, N. C.	-----

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CPO	FS			
		FOREST DISEASE		
FS 2 3-23 (SE)	FS-SE-2305	Air Pollution	Asheville, N. C.	III C, 4-c, 4-d
FS 2 3-24 (SO)	FS-SO-2301	Wood Decay	New Orleans, Louisiana	III C, 6-b, 6-c
FS 2 3-26 (SO)	FS-SO-2302	Bottomland Hardwood Diseases	Stoneville, Miss.	III C, 3-f, 6-b
FS 2 3-25 (SO)	FS-SO-2303	Southern Pine Diseases	Gulfport, Miss.	III C, 2-b, 3-c
FS 2 3-27 (WO)	FS-WO-2301	Cultural Characteristics of Forest Fungi	Laurel, Maryland	III C, 2-d, 6-e
FS 2 3-30 (WO)(Gr)	FS-WO-2302 (Gr)	Biochemistry of Wood Deterioration	New Haven, Connecticut	-----
FS 2 3-29 (WO)(Gr)	FS-WO-2303 (Gr)	Aerobiology of Piedmont Forest Fungi	Durham, North Carolina	-----
FS 3 2-10 (FPL)	FS-FPL-3210	Wood Fungus and Insect Effects and Contorl	Madison, Wisconsin	III C, 6-b, 6-e
P.L. 480				
A6-FS-3		Important Epidemic Diseases of Forest Trees in Taiwan	Taipei, Taiwan	III C, 1-e, 3-d, 4-e, 5-b
A7-FS-5		Accelerated Laboratory Investigations of Durability of Wood	Dehra Dun, India	III C, 6-d
A7-FS-28		Biochemical Studies of the Loranthaceae	Lucknow, India	-----
A7-FS-30		Studies of Wood-Rotting Fungi of West Bengal	Calcutta, India	-----
E15-FS-5		Biology and Epidemiology of Pine Twist Rust	Florence, Italy	III C, 4-g
E21-FS-3		Disease Susceptibility of Some North American Tree Species in Poland	Warsaw, Poland	III C, 1-c
E21-FS-16		Saprophytic and Phytopathogenic Fungi and Their Relations in Forest Soils	Poznan, Poland	III C, 2-a
E21-FS-21		Forest Tree Seed Disease Organisms	Warsaw, Poland	III C, 1-c
E25-FS-5		Diseases of Native Fir, Pine, and Introduced Pinus radiata acclimatized in Spain	Madrid, Spain	III C, 4-d
S3-FS-7		Disease Susceptibility of Some North American Tree Species in Sao Paulo	Sao Paulo, Brazil	-----
S5-FS-1		Disease Susceptibility of Some North American Tree Species in Colombia	Medellin, Colombia	-----
S9-FS-1		Disease Susceptibility of Some North American Tree Species in Uruguay	Montevideo, Uruguay	-----

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CPO	FS			
		WOOD QUALITY RESEARCH		
FS 3 1-1 (FPL)	FS-FPL-3101	Wood structure and identification	Madison, Wisconsin	IV, A-1-a
FS 3 1-2 (FPL)	FS-FPL-3102	Fine wood structure	Madison, Wisconsin	IV, A-1-b
FS 3 1-3 (FPL)	FS-FPL-3103	Wood structure-wood property relations	Madison, Wisconsin	IV, A-1-c
FS 3 1-4 (FPL)	FS-FPL-3104	Environmental, growth, and silvicultural effects	Madison, Wisconsin	IV, A-1-d
FS 3 1-5 (FPL)	FS-FPL-3105	Wood quality evaluation and genetic effects	Madison, Wisconsin, Rio Piedras, P.R., and Ft. Collins, Colorado	IV, A-1-e
FS 3 1-6 (FPL)	FS-FPL-3106	Log and tree grade development	Madison, Wisconsin	IV, A-1-f
FS 3 1-7 (FPL)	FS-FPL-3107	Lumber quality yield development	Madison, Wisconsin, Athens, Georgia, and Carbondale, Illinois	--
FS 3 1-8 (FPL)	FS-FPL-3108	Sawmill improvement	Madison, Wisconsin	IV, A-2-i
FS 3 1-9 (PNW)	FS-PNW-3101	Douglas-fir (and associated species) log and tree grades	Portland, Oregon	IV, A-1-f
FS 3 1-10 (PSW)	FS-PSW-3101	Western pine (and associated speices) log and tree grades	Berkeley, California and Ft. Collins, Colorado	IV, A-1-f
FS 3 1-11 (CS)	FS-CS-3101	Hardwood log and tree grades	Columbus, Ohio	IV, A-1-f
FS 3 1-12 (NE)	FS-NE-3101	Northern softwoods log and tree grades	Upper Darby, Pa.	IV, A-1-f
FS 3 1-13 (SE)	FS-SE-3101	Southern softwoods log and tree grades	Asheville, N. Carolina	IV, A-1-f
		SOLID WOOD PRODUCTS RESEARCH		
FS 3 2-1 (FPL)	FS-FPL-3201	Machining and veneer cutting	Madison, Wisconsin and Alexandria, La.	IV, A-2-a
FS 3 2-2 (FPL)	FS-FPL-3202	Product and process development	Madison, Wisconsin	--
FS 3 2-3 (FPL)	FS-FPL-3203	Wood drying	Madison, Wisconsin, Ogden, Utah, Athens, Georgia, Asheville, N.C., and Rio Piedras, P.R.	IV, A-2-b
FS 3 2-4 (FPL)	FS-FPL-3204	Glues and gluing processes	Madison, Wisconsin	IV, A-2-c
FS 3 2-5 (FPL)	FS-FPL-3205	Glued wood products	Madison, Wisconsin, Alexandria, La., and New Orleans, La.	IV, A-2-d
FS 3 2-6 (FPL)	FS-FPL-3206	Wood finishing	Madison, Wisconsin	IV, A-2-e
FS 3 2-7 (FPL)	FS-FPL-3207	Fire performance of wood	Madison, Wisconsin	IV, A-2-f
FS 3 2-8 (FPL)	FS-FPL-3208	Environmental effects	Madison, Wisconsin	IV, A-2-g
FS 3 2-9 (FPL)	FS-FPL-3209	Preservative development and treating processes	Madison, Wisconsin and Rio Piedras, P.R.	IV, A-2-h
FS 3 2-10 (FPL)	FS-FPL-3210	Wood fungus and insects effects and control	Madison, Wisconsin	III, B-5

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CPO	FS			
		WOOD FIBER PRODUCTS RESEARCH		
FS 3 3-1 (FPL)	FS-FPL-3301	Pulping process investigations	Madison, Wisconsin	IV, A-3-a
FS 3 3-2 (FPL)	FS-FPL-3302	Pulp properties	Madison, Wisconsin	IV, A-3-b
FS 3 3-3 (FPL)	FS-FPL-3303	Fiber processing	Madison, Wisconsin	IV, A-3-c
FS 3 3-4 (FPL)	FS-FPL-3304	Papermaking processes	Madison, Wisconsin	IV, A-3-d
FS 3 3-5 (FPL)	FS-FPL-3305	Converted paper products	Madison, Wisconsin	--
		WOOD CHEMISTRY RESEARCH		
FS 3 4-1 (FPL)	FS-FPL-3401	Wood carbohydrates and conversion products	Madison, Wisconsin	IV, A-4-a
FS 3 4-2 (FPL)	FS-FPL-3402	Lignin structure and utilization	Madison, Wisconsin	IV, A-4-b
FS 3 4-3 (FPL)	FS-FPL-3403	Chemistry of wood and bark extractives	Madison, Wisconsin	IV, A-4-c
FS 3 4-4 (FPL)	FS-FPL-3404	Biochemistry of wood constituents	Madison, Wisconsin	IV, A-4-d
FS 3 4-5 (FPL)	FS-FPL-3405	Surface and polymer chemistry of wood	Madison, Wisconsin	IV, A-4-e
FS 3 4-6 (FPL)	FS-FPL-3406	Process development	Madison, Wisconsin	IV, A-4-f
FS 3 4-7 (FPL)	FS-FPL-3407	Analytical development, instrumentation, and service	Madison, Wisconsin	IV, A-4-g
		WOOD ENGINEERING RESEARCH		
FS 3 5-1 (FPL)	FS-FPL-3501	Fundamental wood properties	Madison, Wisconsin	IV, A-5-a
FS 3 5-2 (FPL)	FS-FPL-3502	Properties of wood-base and related materials	Madison, Wisconsin	--
FS 3 5-3 (FPL)	FS-FPL-3503	Analytical mechanics	Madison, Wisconsin	IV, A-5-b
FS 3 5-4 (FPL)	FS-FPL-3504	Research equipment and method development	Madison, Wisconsin	--
FS 3 5-5 (FPL)	FS-FPL-3505	Design criteria	Madison, Wisconsin	IV, A-5-c
FS 3 5-6 (FPL)	FS-FPL-3506	Structural utilization	Madison, Wisconsin	IV, A-5-d
FS 3 5-7 (FPL)	FS-FPL-3507	Packaging	Madison, Wisconsin	IV, A-5-e
		REGIONAL UTILIZATION PROBLEMS		
FS 3 6-1 (SE)	FS-SE-3601	Utilization improvement, SE	Asheville, N.C.	IV, A-2-b
FS 3 6-2 (SE)	FS-SE-3602	Characterization of southern hardwoods and associated species	Athens, Georgia	--
FS 3 6-3 (SE)	FS-SE-3603	Southern hardwood utilization	Athens, Georgia	IV, A-2-b
FS 3 6-4 (CS)	FS-CS-3601	Utilization improvement, CS	Columbus, Ohio	IV, A-6
FS 3 6-5 (CS)	FS-CS-3602	Using Central States timber	Carbondale, Illinois	--
FS 3 6-6 (NE)	FS-NE-3601	Utilization improvement, NE	Upper Darby, Pa.	IV, A-6
FS 3 6-7 (ITF)	FS-ITF-3601	Timber utilization, Tropics	Rio Piedras, P.R.	IV, A-2-h, A-1-e, A-2-b, A-6
FS 3 6-8 (LS)	FS-LS-3601	Timber characterization and processing	Wausau, Wisconsin	IV, A-1-f
FS 3 6-9 (LS)	FS-LS-3602	Utilization improvement, LS	St. Paul, Minnesota	IV, A-6
FS 3 6-11 (PNW)	FS-PNW-3601	Utilization improvement, PNW	Portland, Oregon	IV, A-6
FS 3 6-13 (PSW)	FS-PSW-3601	Utilization improvement, PSW	Berkeley, California	IV, A-6

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CPO	FS			
		REGIONAL UTILIZATION PROBLEMS		
FS 3 6-15 (INT)	FS-INT-3601	Utilization improvement, INT and Northern Region	Ogden, Utah	IV, A-2-b
FS 3 6-17 (RM)	FS-RM-3601	Utilization improvement, RM	Fort Collins, Colorado	IV, A-1-e, A-6
FS 3 6-19 (SO)	FS-SO-3601	Utilization improvement, SO	New Orleans, Louisiana	IV, A-2-a, A-2-d, A-6
		FOREST ENGINEERING RESEARCH		
FS 3 7-1 (INT)	FS-INT-3701	Engineering systems for steep mountain forestry	Bozeman, Montana	IV, B-1
FS 3 7-2 (LS)	FS-LS-3701	Engineering systems for northern hardwoods	Houghton, Michigan	IV, B-2
FS 3 7-3 (SO)	FS-SO-3701	Engineering systems for intensive forest management	Auburn, Alabama	--
FS 3 7-4 (PNW)	FS-PNW-3701	Engineering systems for heavy timber stands in the Pacific Northwest and Alaska	Seattle, Washington	IV, B-3, B-4
		P.L. 480 PROJECTS		
E8-FS-9		Factors affecting the impregnability of wood	Helsinki, Finland	IV, A-2-k
E8-FS-10		Moisture-temperature-time-strength relations, etc.	Helsinki, Finland	IV, A-5-f
E8-FS-18		Accessibility studies of cellulose fiber	Helsinki, Finland	IV, A-4-h
E8-FS-39		Aerobic bacterial degradation of lignin	Helsinki, Finland	IV, A-4-h
S8-FS-1		Collection of wood samples, etc. from forest trees of Peru	Lima, Peru	IV, A-1-h
A17-FS-2		Investigation and evaluation of factors influencing the absorption, etc. in tropical timber	Sholashahar, Chittagong, East Pakistan	IV, A-2-1
A17-FS-7		Collection of wood samples, etc. from trees in East Pakistan	Sholashahar, Chittagong, East Pakistan	IV, A-1-i
A7-FS-3		Working qualities of Indian timbers	Dehra Dun, India	IV, A-2-j

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CPO	FS			
FS 4 1	FS 4 1	FOREST SURVEY		V
FS 4 1-1 (NOR)	FS-NOR-4101	Forest Survey-NOR	Juneau, Alaska	V, A-a
FS 4 1-2 (PNW)	FS-PNW-4101	Forest Survey-PNW	Portland, Oregon	V, A-a,d
FS 4 1-3 (PNW)	FS-PNW-4102	Survey Techniques-PNW	Portland, Oregon	V, A-h
FS 4 1-4 (PSW)	FS-PSW-4101	Forest Survey-PSW	Berkeley, California	V, A-a
FS 4 1-5 (INT)	FS-INT-4101	Forest Survey-INT	Ogden, Utah	V,A-a,e,f
FS 4 1-6 (LS)	FS-LS-4101	Forest Survey-LS	St. Paul, Minnesota	V, A-a,g
FS 4 1-7 (NE)	FS-NE-4101	Forest Survey-NE	Upper Darby, Pennsylvania	V, A-a,b
FS 4 1-8 (SO)	FS-SO-4101	Forest Survey-SO	New Orleans, Louisiana	V, A-a,d,g,
FS 4 1-9 (SE)	FS-SE-4101	Forest Survey-SE	Asheville, North Carolina	V, A-a,c
FS 4 1-10 (WO)	FS-WO-4101	Forest Survey-WO	Washington, D.C.	
FS 4 2	FS 4 2	FOREST ECONOMICS		V
FS 4 2-1 (PNW)	FS-PNW-4201	Production Economics-PNW	Portland, Oregon	V, B-a,c,i
FS 4 2-2 (PNW)	FS-PNW-4202	Multiple-Use-PNW	Portland, Oregon	V, B-l
FS 4 2-4 (PSW)	FS-PSW-4201	Production Economics-PSW	Berkeley, California	
FS 4 2-5 (PSW)	FS-PSW-4202	Multiple-Use-PSW	Berkeley, California	V, B-m
FS 4 2-7 (INT)	FS-INT-4201	Production Economics-INT	Ogden, Utah	
FS 4 2-8 (INT)	FS-INT-4202	Multiple-Use-INT	Ogden, Utah	V, B-j
FS 4 2-9 (RM)	FS-RM-4201	Watershed Economics-RM	Flagstaff, Arizona	V, B-k
FS 4 2-11 (LS)	FS-LS-4201	Production Economics-LS	Grand Rapids, Minnesota	V, B-f
FS 4 2-12 (LS)	FS-LS-4202	Small Woodland Ownerships-LS	St. Paul, Minnesota	
FS 4 2-13 (CS)	FS-CS-4201	Production Economics-CS	Columbus, Ohio	
FS 4 2-14 (CS)	FS-CS-4202	Small Woodland Ownerships-CS	Columbus, Ohio	V, B-d,h
FS 4 2-15 (SO)	FS-SO-4201	Production Economics-SO	New Orleans, Louisiana	V, B-e
FS 4 2-16 (SO)	FS-SO-4202	Small Woodland Ownerships-SO	New Orleans, Louisiana	
FS 4 2-18 (NE)	FS-NE-4201	Production Economics-NE	Upper Darby, Pennsylvania	V, B-b,g
FS 4 2-19 (NE)	FS-NE-4202	Small Woodland Ownerships-NE	Upper Darby, Pennsylvania	
FS 4 2-22 (SE)	FS-SE-4201	Production Economics-SE	Asheville, North Carolina	
FS 4 2-25 (WO)	FS-WO-4202	Forest Finance-WO	Washington, D.C.	